MONTHLY WEATHER REVIEW

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NOTICE OF CHANGE IN MONTHLY WEATHER REVIEW

The monthly climatological data tables carried in the Monthly Weather Review through December 1949 now appear in "Climatological Data, National Summary"

DEPARTMENT OF COMMERCE
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WEATHER BUREAU
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TORNADOES IN OKLAHOMA, 1875-1949

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INTRODUCTION

Three outstanding tornado records, one in each of the past 3 years, were established in Oklahoma. In 1949, 58 tornadoes occurred, by far the greatest number for any year in the State. In 1948, two tornadoes only 5 days apart (on Mar. 20 and 25) struck Tinker Field near Oklahoma City with extensive damage to aircraft. Losses from the March 20 tornado were estimated at $10,250,000, the greatest loss to property for any single tornado in Oklahoma. On March 25, property loss was estimated at $6,100,000, the third greatest loss to property. The most disastrous storm ever to strike in this section of the country occurred on April 9, 1947, when a tornado swept over a 221-mile path from White Deer, Tex., through northwestern Oklahoma, and into Kansas. In the 3 States, 169 persons were killed, 980 were injured, and property damage was estimated at $9,700,000. Principal damage by this storm was at Woodward, Okla., where 95 persons were killed, and over $6,600,000 damage occurred.

These record-setting storms resulted in considerable publicity for tornadoes in Oklahoma, and brought many requests for data on previous tornadoes in the State. As previous data were not complete, a detailed tabulation was prepared by the writer at the Weather Bureau Office, Oklahoma City. All sources of information at the Weather Bureau Office were used and a number of items were checked in early newspapers on file at the Oklahoma Historical Society as well as newspapers in the file room of the Daily Oklahoman and Oklahoma City Times. A number of references were also obtained from the Library at the Weather Bureau Central Office in Washington. While the tabulation is detailed, and is complete as far as is known, additional tornadoes likely occurred, especially in the earlier years, for which no record was published.

The original tabulation covering the years 1875-1947 was made following the catastrophe in 1947; it was recently extended to include the tornadoes of 1948 and 1949. It is the purpose of the present paper to present the following brief summary of the detailed tabulation.[1]

SUMMARY OF TORNADO DATA

Table 1 lists the number of tornadoes and the resulting deaths, injuries, and estimated property losses for the period from 1875 through 1949. In all, 469 tornadoes were listed, 924 lives lost, and more than 4,106 persons injured. Property losses were estimated to total more than $51,400,000, not including damage which could not be estimated for many of the tornadoes of the early years.

It is pointed out that data of earlier years and recent years are not comparable. This may be due to a number of reasons. In the early days many tornadoes would go by unnoticed due to the sparsity of population, or unreported due to lack of communication facilities. The chances that a tornado will cause death and injury are much greater now that the population has increased many times. There is also a great increase in the amount and valuation of property. An example that shows that much greater losses would occur in more recent years, is the

[1] The detailed tabulation gives place, date and time of occurrence, direction of movement, length and width of path, loss of life and property, injuries, and other items of interest for each tornado reported in Oklahoma during the period 1875-1949. The tabulation, "Tornadoes in Oklahoma, 1875-1949," which is in manuscript form, is on file in the Weather Bureau Office, Oklahoma City, Okla., and in the Weather Bureau Library, Washington, D. C.

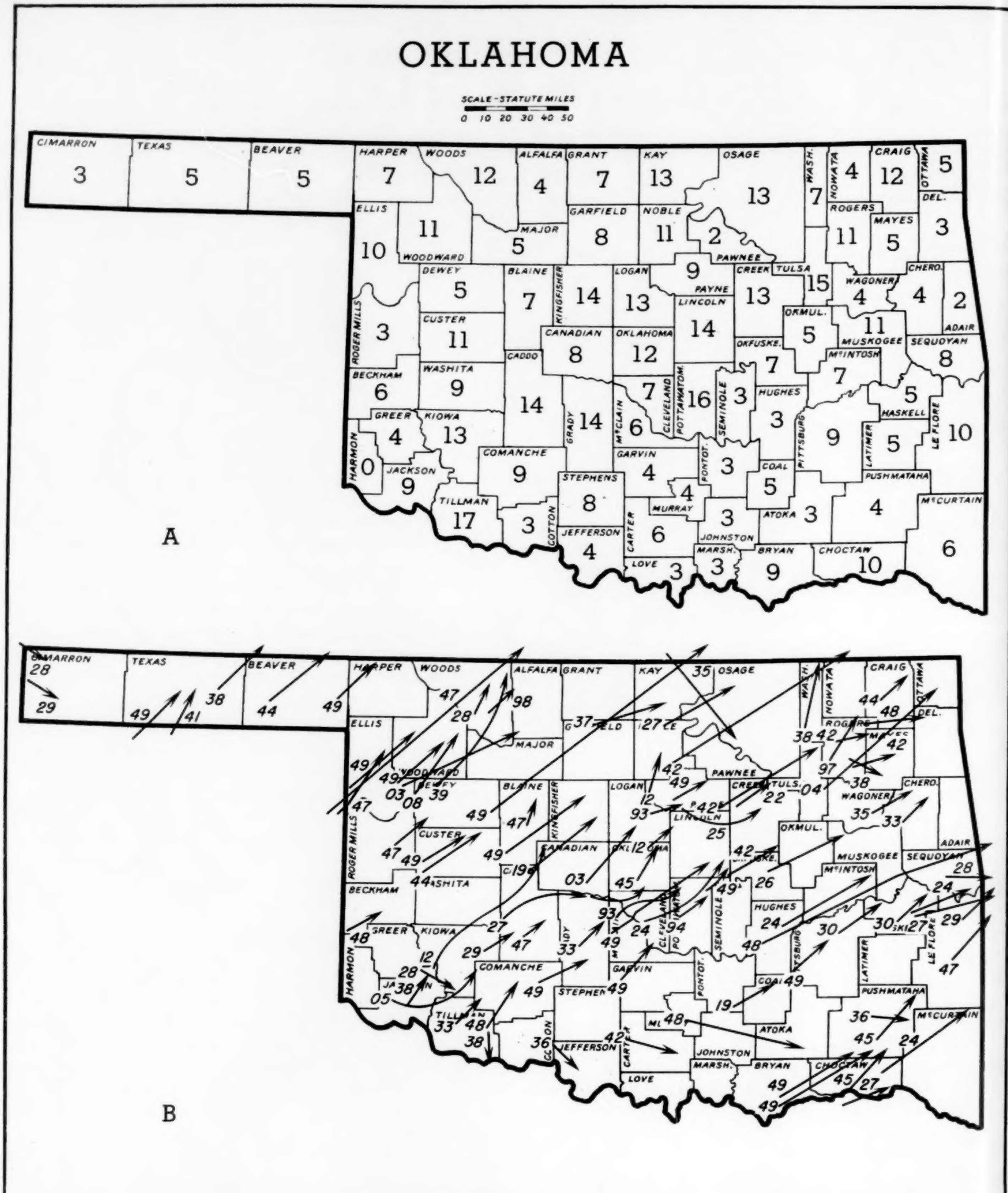

FIGURE 1.—(a) Number of times tornadoes have been recorded in each county in Oklahoma, 1875–1949. (b) Tornado paths 15 miles or longer, 1875–1949. Number by each path indicates last two digits of year of occurrence; arrow shows direction of movement. Widths of paths are not drawn to scale.

TABLE 1.—*Number of tornadoes, deaths, injuries, and property losses by years in Oklahoma, 1875–1949**

Year	Number of tornadoes†	Deaths	Injuries	Property losses
1949	58	16	168	$4,035,060
1948	19	17	264	17,506,000
1947	12	111	812	9,356,000
1946	10	2	19	1,279,500
1945	18	104	725	4,550,100
1944	22	3	74	778,500
1943	8	4	25	63,200
1942	15	114	**250	2,687,300
1941	8	1	10	216,000
1940	5	0	5	52,450
1939	1	7	19	104,000
1938	13	0	27	305,112
1937	6	4	18	266,500
1936	21	20	140	410,325
1935	15	1	49	312,280
1934	11	4	49	340,100
1933	10	11	56	410,500
1932	2	0	0	255,000
1931	3	4	8	85,000
1930	19	35	94	649,600
1929	11	3	5	511,500
1928	8	10	34	1,583,000
1927	11	20	87	547,500
1926	4	8	64	239,000
1925	8	2	11	101,000
1924	7	25	106	1,308,000
1923	9	2	15	112,500
1922	9	23	87	1,050,000
1921	1	0	0	75,000
1920	5	64	89	385,000
1919	8	25	70	545,000
1918	3	3	5	(1)
1917	19	36	121	(1)
1916	4	9	28	(1)
1915	0	0	0	0
1914	1	0	0	50,000
1913	0	0	0	0
1912	13	29	95	**643,525
1911	5	10	85	132,000
1910	2	2	4	15,000
1909	4	4	11	(1)
1908	8	9	45	(1)
1907	0	0	0	0
1906	0	0	0	0
1905	8	105	109	284,000
1904	3	5	31	(1)
1903	8	4	36	(1)
1902	0	0	0	0
1901	0	0	0	0
1900	0	0	0	0
1899	2	0	Several	(1)
1898	5	2	24	(1)
1897	2	15	48	103,000
1896	10	5	**8	(2) 300
1895	0	0	0	(2) 0
1894	3	1	Many	(2) 2,000
1893	5	40	**25	(2) 60,000
1892	1	1	3	(2) 2,000
1891				
1890				
1889				
1888	1	0	Small number	
1887				
1886				
1885	1	0	0	
1884	1	0	0	
1883				
1882	2	4	48	
1881				
1880				
1879				
1878				
1877				
1876				
1875	1			
Total	469	924	**4,106	**51,411,852

*Complete as far as is known, but additional unrecorded tornadoes probably occurred in the earlier years.
†Straight line damaging winds not included.
** Plus additional numbers or losses.
[1] Considerable damage, monetary amount not determined.
[2] Losses as reported by A. J. Henry in his article, "Tornadoes, 1889–96" in Report of Chief of Weather Bureau, 1895–96.

tornado of considerable force that cut a path 6 miles long from a point 3 miles northwest of downtown Oklahoma City to a point 2 miles south of Britton, Okla., on May 12, 1896. This tornado caused no injuries and only $300 property damage. It would be difficult to imagine the death and damage that would result if such a well developed tornado struck in the same path 50 years later, going through this residential area where many of the finest homes in Oklahoma City are now located.

For the last 30 years, 1920 through 1949, the data are more comparable. During these years, tornadoes occurred on an average of 11 per year, with average annual losses of 20 deaths, 112 injuries, and about $1,600,000 property damage. The greatest number of tornadoes in any year was 58 in 1949. Only one tornado occurred in each of the years 1921 and 1939. Death losses per year ranged from none in four of the last 30 years to 114 in 1942. There were no injuries in 1921 and in 1931; there were 812 persons injured in 1947. Property damage per year for the past 30 years ranged from about $50,000 in 1940 to more than $17,500,000 in 1948.

Figure 1 (a) shows the number of times tornadoes have been recorded in each county. Tornadoes that moved through two or more counties were recorded for each county affected. For those storms that occurred before the present county boundaries were established, the location was used to determine in which of the present counties it would have occurred. All sections of the State have experienced tornadoes with the exception of Harmon County in the extreme southwestern part of the State. The greatest number of tornadoes recorded in any county is 17 in Tillman County; there have been 16 in Pottawatomie County, and 15 in Tulsa County.

Table 2 lists the number of times tornadoes have occurred in each month. About two-thirds of all tornadoes occurred between April 8 and June 9. May, with 162 occurrences, is the month in which tornadoes occurred most frequently, followed by April with 111. Tornadoes have occurred every month of the year in Oklahoma, although only three have been reported in December.

TABLE 2.—*Tornado occurrences in each month in Oklahoma, 1875–1949.*

January	February	March	April	May	June	July	August	September	October	November	December	Total
14	10	50	111	162	68	7	7	9	16	12	3	469

Tornadoes have occurred every hour of the day in Oklahoma, but most frequently (about three-fourths of the time) between 2 p. m. and 9 p. m., local time. They are least likely to occur in the early morning between 4 a. m. and 9 a. m., although several of the more severe tornadoes that have occurred in the fall and winter in Oklahoma struck between midnight and noon.

TABLE 3.—*Tornadoes in Oklahoma causing greatest loss of life (number injured in these storms also listed)*

Principal place or places	Date of tornado	Number dead	Number injured
Ellis County and Woodward	Apr. 9, 1947	*101	*782
Snyder	May 10, 1905	97	58
Antlers	Apr. 12, 1945	69	353
Peggs	May 2, 1920	60	80
Pryor	Apr. 27, 1942	52	181
Oklahoma City	June 12, 1942	35	29
Southwest of Moore	Apr. 25, 1893	31	Many
Bethany	Nov. 19, 1930	23	77
Childsville	May 2, 1942	16	Many
Richville, Vireton	Jan. 4, 1917	15	8 or more
Lugert, Hobart, Colony, Calumet	Apr. 27, 1912	15	39
Chandler	Mar. 30, 1897	14	40
Muskogee	Apr. 12, 1945	13	113
Roberta, Durant	Apr. 9, 1919	*11	*20
Colgate	June 1, 1917	11	75
Gowen	Mar. 13, 1922	10	24

*Additional number dead and injured in adjacent States.

TABLE 4.—*Tornadoes in Oklahoma causing an estimated property loss of $1,000,000 or more*

Principal place or places	Date of tornado	Estimated property losses
Tinker Field	Mar. 20, 1948	$10, 250, 000
Ellis County and Woodward	Apr. 9, 1947	*8, 022, 750
Tinker Field	Mar. 25, 1948	6, 100, 000
Pryor	Apr. 27, 1942	2, 000, 000
Antlers	Apr. 12, 1945	1, 525, 000
Blair and Headrick	June 16, 1928	(in excess of) 1, 500, 000
Muskogee	Apr. 12, 1945	1, 400, 000
Oklahoma City	do	1, 000, 000
Leedey	May 31, 1947	(in excess of) 1, 000, 000
Ardmore	Feb. 13, 1946	1, 000, 000

*Additional losses in Texas and Kansas.

Direction of movement of tornadoes is usually toward the northeast, less frequently east or southeast. Occasionally tornadoes travel in some other direction. They usually travel in a straight path, although sometimes they change direction. The disastrous tornado that struck Oklahoma City in June 1942, which was observed by many persons including Weather Bureau Airport personnel, followed a path almost a half circle curving from the southeast to the southwest, then east, then north. A tornado in Caddo County in June 1949 circled an area of 1 mile radius. In May 1949, a tornado approached the town of Schulter from the southwest, then after it struck the town it appeared to move out of town in a southeast direction.

Tornado paths are usually short and less than 10 miles in length although paths of over 50 miles have occurred a number of times. The Woodward tornado in 1947 had a path 101 miles long in Oklahoma alone, while the Pawhuska storm in 1942 was 100 miles long. Figure 1 (b) shows tornado paths 15 miles or more in length. Length, direction of movement, and year of occurrence are indicated.

Tornadoes are localized in nature, usually covering a very limited area. Most of these "twisters" are less than 440 yards wide, although paths over 2 miles in width have been reported. The tornado path at Woodward on April 9, 1947, was 1.8 miles wide.

Chances for experiencing a tornado are slight. For example, in the last 60 years, there have been 12 tornadoes in Oklahoma County affecting a total area in these 60 years of less than 14 square miles. Tornadoes do not seem to follow any particular pattern or paths although they may strike the same area more than once. In Ellis County in 1947, five farmsteads, partially rebuilt following the April 9 tornado, were wrecked again when another tornado visited the same area on May 31 that same year. The two destructive tornadoes in 1948 that struck Tinker Field were only 5 days apart.

Table 3 lists tornadoes causing 10 or more fatalities, together with the number injured in each storm. Table 4 lists those tornadoes for which property losses were estimated at $1,000,000 or more. It is interesting to note that those causing the greatest property damage occurred in recent years. This can be attributed to the increase in amount and valuation of the property that could be destroyed.

TORNADO "FREAKS"

As may be expected, tornadoes often leave objects in grotesque positions; human reactions to the effects of the tornado and accounts of miraculous escapes are often published. After nearly every major tornado disaster, a number of strange happenings are described by observers. These "freaks" of the storm usually are of one of the following types:

1. The "stripping" effect. A common happening has been for chickens to be left, either alive or dead, without feathers. Persons, living or dead, have had much of their clothing removed. Harnesses have been taken off horses. Trees have been stripped of their limbs and even their bark. "Cats without fur, and dogs without hair" were found after the Snyder tornado.

2. The "scattering" effect. Parts of the same building have been found miles apart. In the Woodward tornado, bodies of two persons, known to have been together, were found 2 miles apart amidst the wreckage of the home in which they were. It has been a common occurrence to find objects miles away from the place where they were picked up by the storm.

3. The "selective" effect. It has been often noted that some objects are carried away while lighter objects next to them are left untouched. Reports have been made of incidents such as that which occurred in the Bethany tornado when a man was unharmed while the chicken house in which he was standing was blown away, and all the chickens were killed.

4. The "carrying" effect. Living creatures, from babies to large horses, have been picked up by the tornado, carried in the air for some distance, and set down unhurt.

5. The "driving" effect. The common occurrence of having straws or shingles driven into boards and trees has been related a number of times. Straws have even been driven into automobile tires between the casing and the wheel.

THE WEATHER AND CIRCULATION OF FEBRUARY 1950[1]

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The general circulation of the entire Northern Hemisphere was considerably more zonal in character in February 1950 than it was during the preceding month. Comparison of mean 700-mb. charts for the 2 months (see fig. 1 of this article and corresponding article in January 1950 Monthly Weather Review) shows that most of the centers of height anomaly were smaller in magnitude in February than in January. During both months the greatest anomaly anywhere on the map was the positive center in the Bering Sea, but even this anomaly decreased from 900 feet in January to 580 feet in February. Of greater significance, perhaps, than the decrease in magnitude of this anomaly center was its motion. The centers of both the positive height anomaly and the associated anticyclone moved about a thousand miles to the northwest during the month. As a result, strong northerly flow on the east side of the High transported extremely cold Alaskan air over the relatively warm waters of the Gulf of Alaska, where a Low center quickly developed, both at sea level and aloft, in the well-known manner first described by Namias.[2]

[1] See charts I-XI, following p. 40, for analyzed climatological data for the month.

[2] J. Namias, and P. F. Clapp, "Studies of the Motion and Development of Long Waves in the Westerlies," *Journal of Meteorology*, vol. 1, No. 3, December, 1944, pp. 57-77.

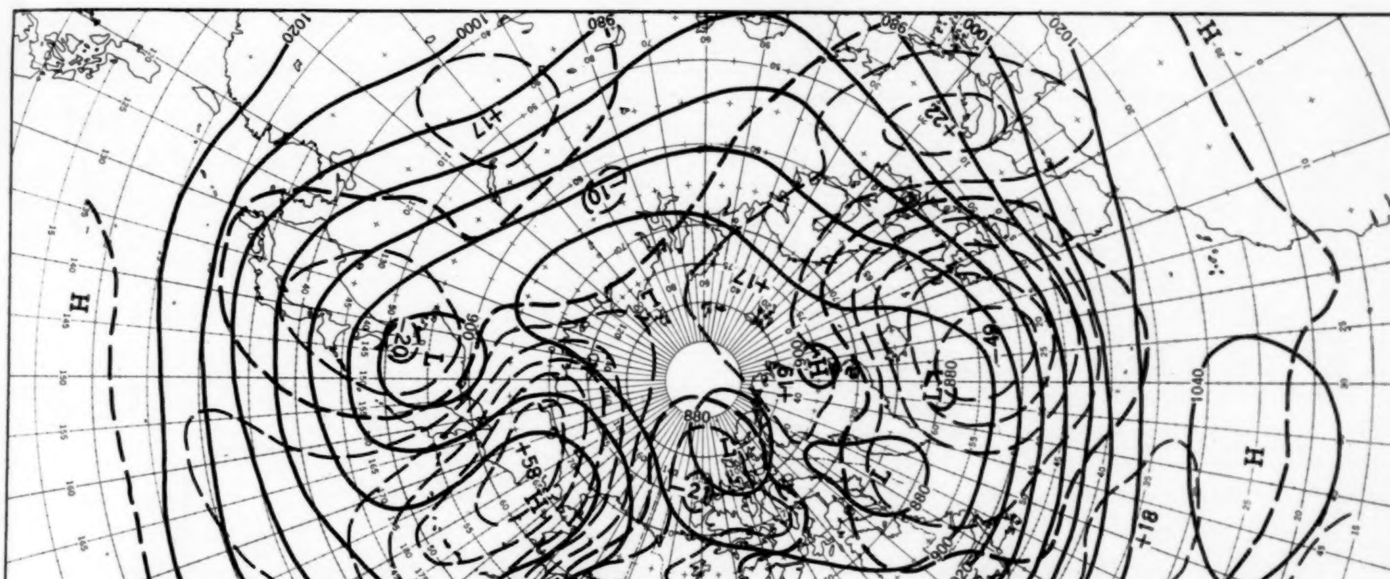

FIGURE 1.—Mean 700-mb. chart for the 30-day period January 28–February 26 inclusive. Contours at 200-foot intervals are shown by solid lines; 700-mb. height departure from normal at 100-mb. intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in 10's of feet.

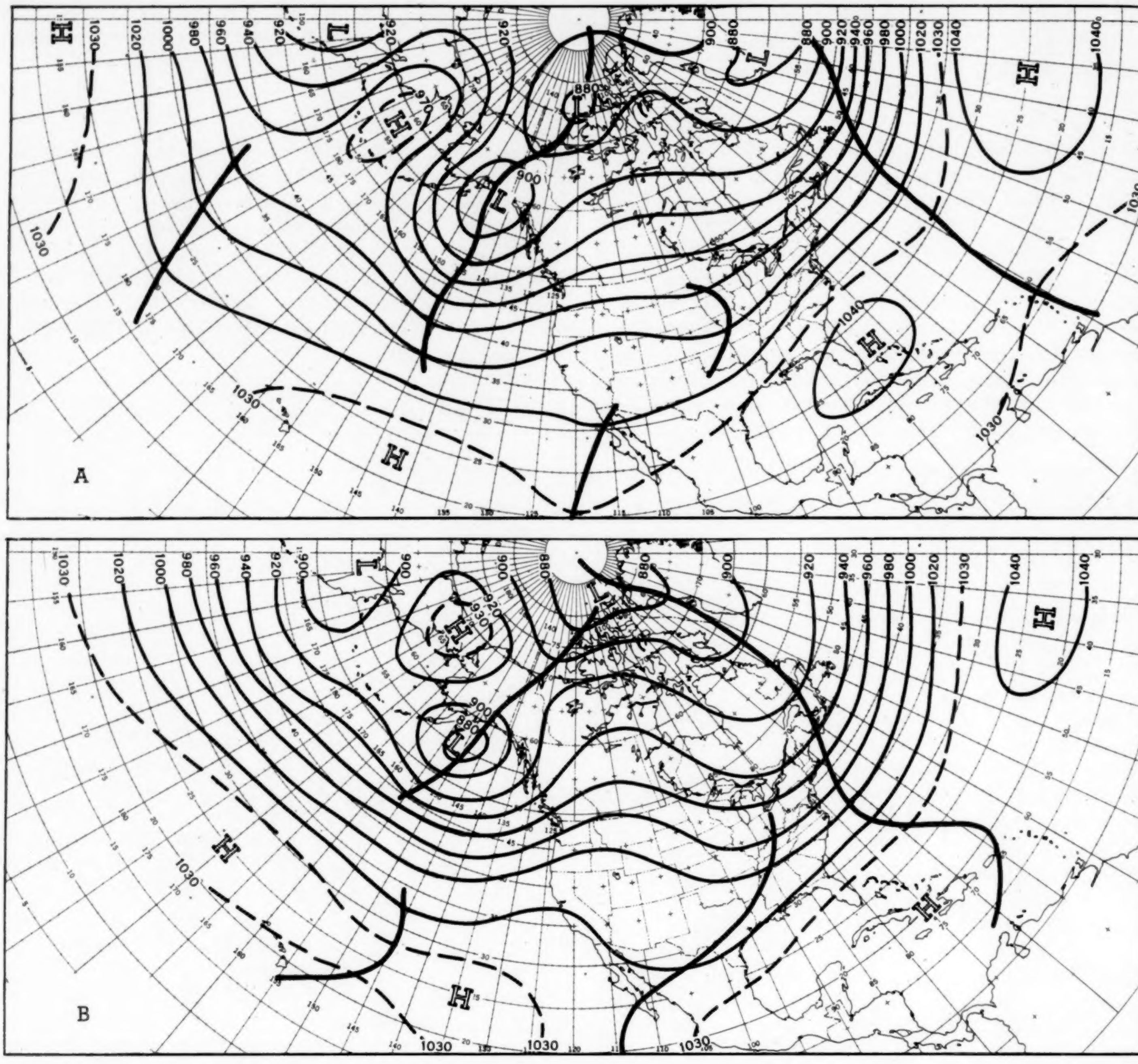

FIGURE 2.—15-day mean 700-mb. charts for (a) February 1-15, and (b) February 12-26. Contours at 200-foot intervals are shown by thin solid lines, selected intermediate contours at 100-foot intervals by dashed lines. Heavy solid lines indicate trough lines drawn through the longitudes where contours reach their minimum latitude.

In response to the formation of the Gulf of Alaska Low, the circulation pattern over North America began to undergo radical readjustment during February. In general agreement with vorticity and wave-length principles, a ridge developed in the western part of North America, and a part of the trough which had occupied this area during January moved eastward into the eastern United States. At the same time the trough which had been located in the central Atlantic in January retrograded sharply toward the east coast of North America during February, and the ridge in the eastern United States weakened considerably. The progressive nature of the deepening of the Gulf of Alaska Low, development of the western North American ridge, eastward motion of the trough in the United States, retrogression of the Atlantic trough, and weakening of the Bermuda High are all well illustrated by comparing the 15-day mean 700-mb. charts for the first and second halves of the month (fig. 2).

Thus February was a month of transition, not only in the general circulation pattern but also in the weekly surface temperature departures from normal (fig. 3).

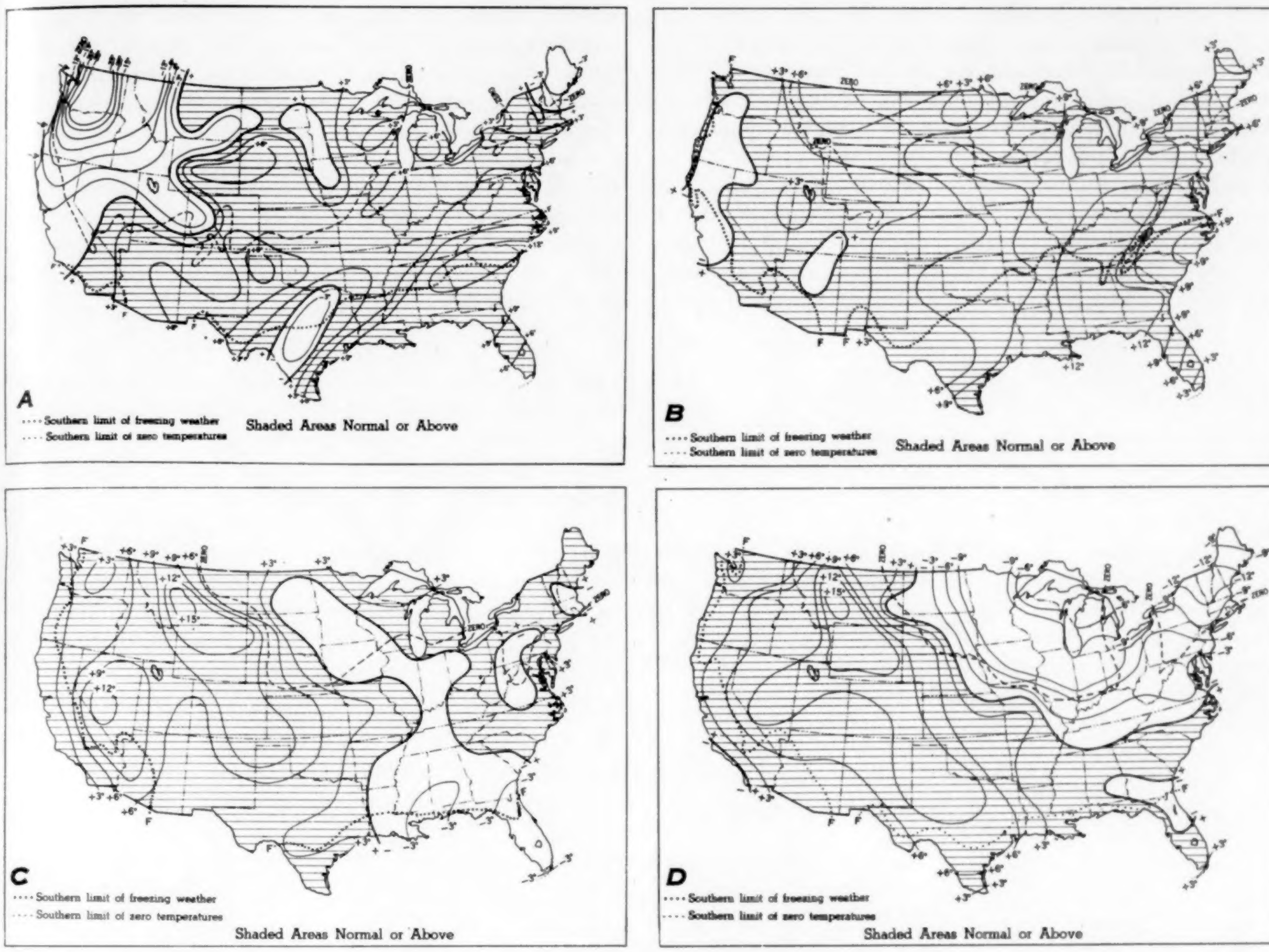

FIGURE 3.—Charts showing departure from normal of the weekly mean temperatures during the month of February; (a) week ending February 7, (b) week ending February 14, (c) week ending February 21, (d) week ending February 28.

The first week of the month was marked by intense cold in the northwestern part of the United States and extreme warmth in the Southeast, a continuation of the January pattern. During the second and third weeks the West became steadily warmer, as a ridge aloft developed in the area, and the East became progressively colder as the Bermuda High weakened and trough conditions intensified. By the last week of February the initial temperature and circulation patterns were completely reversed, with above-normal surface temperatures and 700-mb. heights prevailing in the Southwest while the Northeast was experiencing its coldest weather of the winter season, accompanied by considerable snow and storminess.

As a whole, during the month of February temperatures averaged above normal over most of the United States; temperatures were below normal in only three small northern border areas. (See chart I.) This predominantly mild weather was associated with above-normal 700-mb. heights in nearly all of the country and below-normal heights in the Gulf of Alaska and western Canada. (See fig. 1.) As a result of this distribution of height anomalies, and also in response to strong confluence around 45° N., 155° W., between cold Arctic air flowing from the north and warm Pacific air from the west-southwest, the upper-level westerlies blew with unusual vigor across the United States. The country was therefore flooded with mild Pacific air, and the cold polar continental air masses could not penetrate the border to any appreciable extent. The greatest positive temperature departures from normal were observed in the western Plains, where the foehn effect intensified the warmth of the Pacific air, and to a lesser extent in the Southeast, where warm maritime tropical air was mixed with the mild Pacific air.

The distribution of total precipitation during the month of February was similar in many respects to the January precipitation regime. During both months southwesterly flow just east of a mean 700-mb. trough was associated

with above-normal amounts of precipitation in the Ohio and lower Mississippi valleys, while precipitation was deficient in the Southeast because of the dominance of anticyclonic conditions at all levels of the troposphere. Moreover, stronger-than-normal westerly wind components produced heavy precipitation in the extreme Northwest but created a rain-shadow east of the Rocky Mountains in both January and February. On the other hand, precipitation was considerably reduced during February in most of the northern Plains, northern Plateau, and California, as the trough conditions and below-normal 700-mb. heights which prevailed there in January were replaced by an upper-level ridge and positive height anomalies. These changes were accompanied by a northward shift of the principal cyclone track across the western part of North America, from the United States in January to Canada in February. (See charts III of Monthly Weather Review for January and February 1950.) During both months, however, several storms moved northeastward across the Mississippi and Ohio valleys and produced heavy precipitation and serious flood conditions in many parts of this area.

SOME SYNOPTIC ASPECTS OF A CHANGE IN WEATHER REGIME DURING FEBRUARY 1950

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INTRODUCTION

Beginning near the end of the first week and ending during the third week of February 1950, the weather regime over the United States underwent a complete change from the abnormal conditions which had persisted during January and the early part of February. The change was marked by a moderation of extreme cold in the northwestern portion of the country (and western Canada) and a return from unseasonable warmth to more normal conditions in the East. The transition period was accompanied by a series of storms moving across the United States and Canada, one of which produced the first heavy and lasting snow cover of the season in the northeastern part of the United States. The processes by which a change-over from one regime to another takes place are not fully understood, but in the present discussion some synoptic aspects of the change-over are traced, together with certain associated physical and dynamical factors, with particular emphasis on inertia effects evident in observed upper wind patterns [1,2]. An attempt is made to point out features related to short-term forecasting problems rather than to explain the causes of the change-over.

GENERAL SYNOPTIC FEATURES

The anomalous features of the circulation during the early part of February may be seen by comparing figures 1 and 2. Figure 1 (based on [3,4]) shows the normal sea-level pressure and normal 700-mb. pattern for February, and figure 2 the corresponding average conditions for the first 5 days of February 1950. Figure 2 shows that the cold air flow, which is normally southward across the Hudson Bay area into northeastern United States was displaced far to the westward, resulting in cold weather in western Canada and northwestern United States and mild conditions over the United States east of the Rockies. Other important anomalies in figure 2 include a cold surface High over the Great Basin region, and a large surface High over the Aleutian Islands, the latter being of

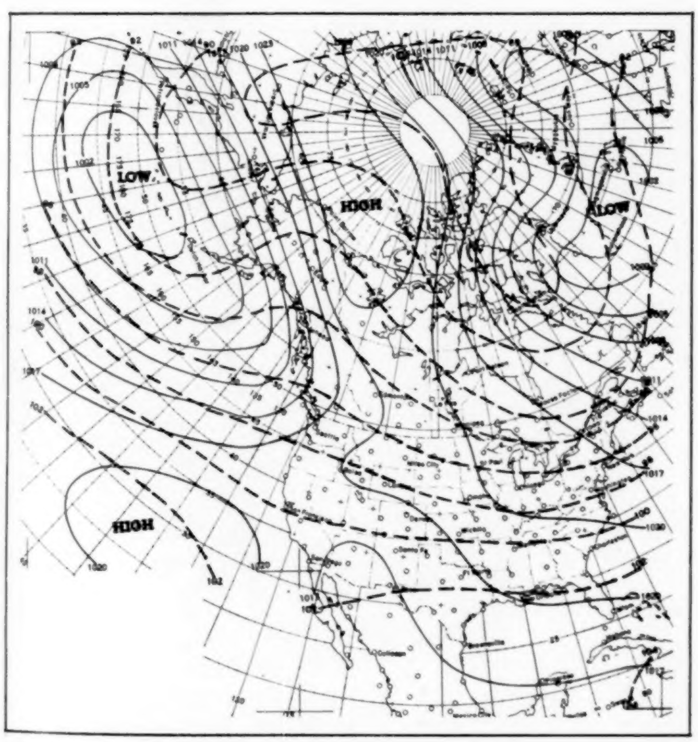

FIGURE 1.—Normal sea level isobars at 3-mb. intervals (solid lines) and 700-mb. contours at 200-foot intervals (dashed lines labeled in hundreds of feet) for the month of February.

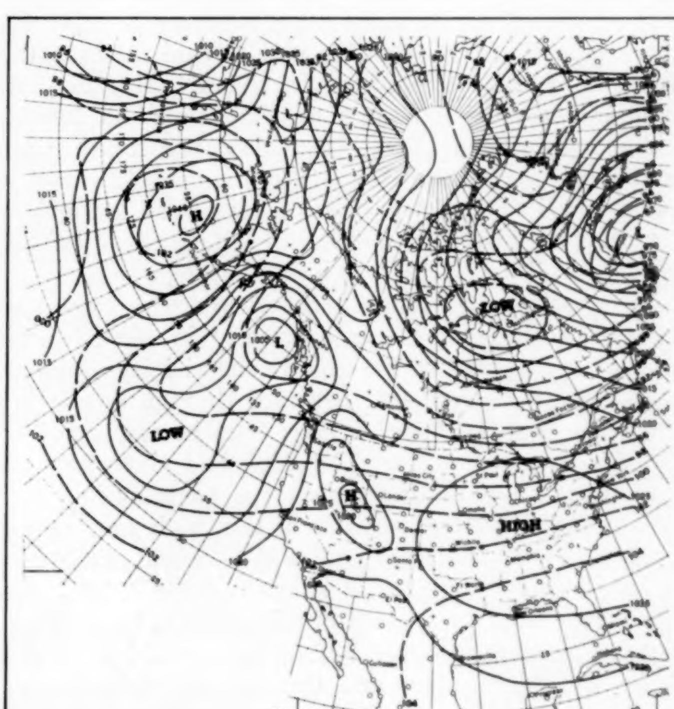

FIGURE 2.—Mean sea level isobars at 5-mb. intervals (solid lines) and 700-mb. contours at 200-foot intervals (dashed lines labeled in hundreds of feet) for the period February 1-5, 1950.

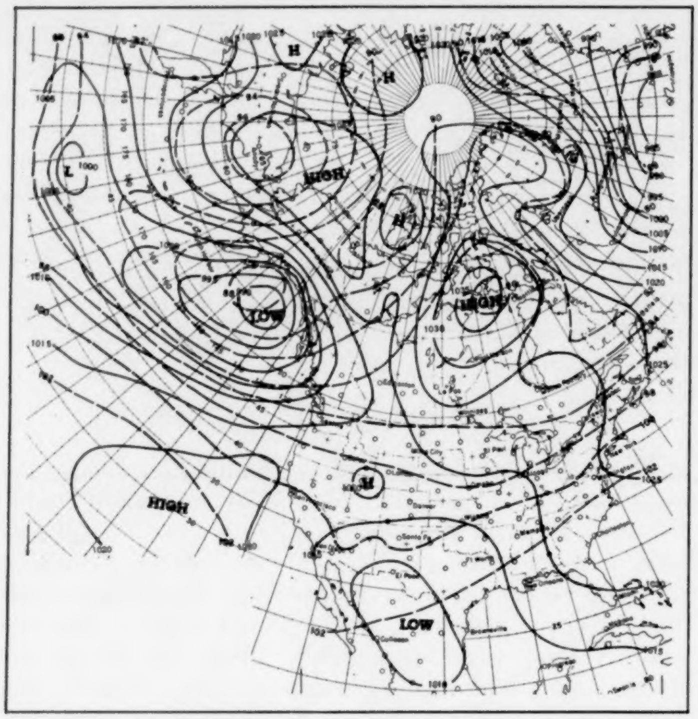

FIGURE 3.—Mean sea level isobars at 5-mb. intervals (solid lines) and 700-mb. contours at 200-foot intervals (dashed lines labeled in hundreds of feet) for the period February 8-12, 1950.

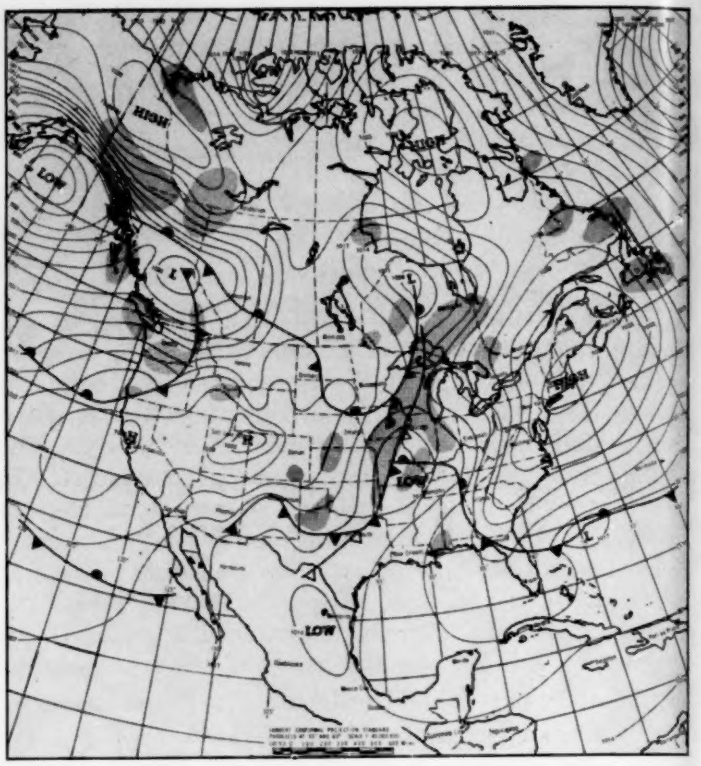

FIGURE 4.—North American surface map for 1830 GMT, February 8, 1950. Shading indicates areas of active precipitation.

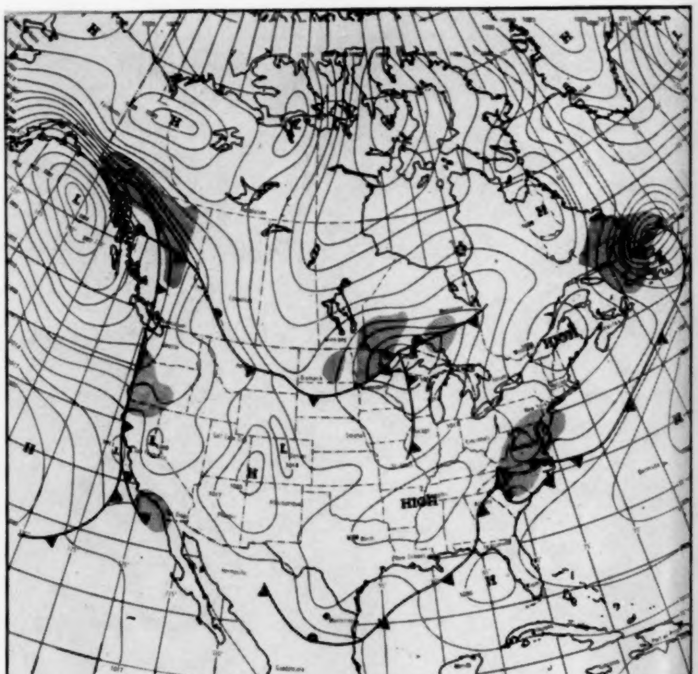

FIGURE 5.—North American surface map for 1830 GMT, February 10, 1950. Shading indicates areas of active precipitation.

particular importance in separating normally low pressure in the Aleutian region into two Low cells, one near Japan and the other in the Gulf of Alaska.

Figure 3 shows the mean sea-level pressure and mean height of the 700-mb. surface for February 8–12, 1950. There was still no appreciable flow of cold air from the Hudson Bay area into northeastern United States; instead, cold air was moving around a High which had formed in the Hudson Bay region. The High near Salt Lake City had moved southeastward since the early part of February, and a new Pacific air mass was moving into the region. Temperatures had moderated in the Pacific northwest where a new and weaker surface High was forming.

A very significant change had occurred with respect to the surface High that was previously in the Aleutian region. A break-off of the Low in the vicinity of Japan had moved northward and eastward through the Bering Sea, separating the Aleutian High from its connection to the Siberian anticyclone. The High had given way toward the southeast and was decreasing rapidly in intensity. Cold air on the east side of this High was feeding partly into the Low in the Gulf of Alaska and partly into an eastward-moving Low at about latitude 35° N. On February 8 (fig. 4) a portion of this cold air, its temperature modified by the ocean trajectory, moved into British Columbia, Washington, and Oregon, and subsequently moved eastward across the country accompanied by a Low which passed over the Great Lakes region and skirted the Hudson Bay High.

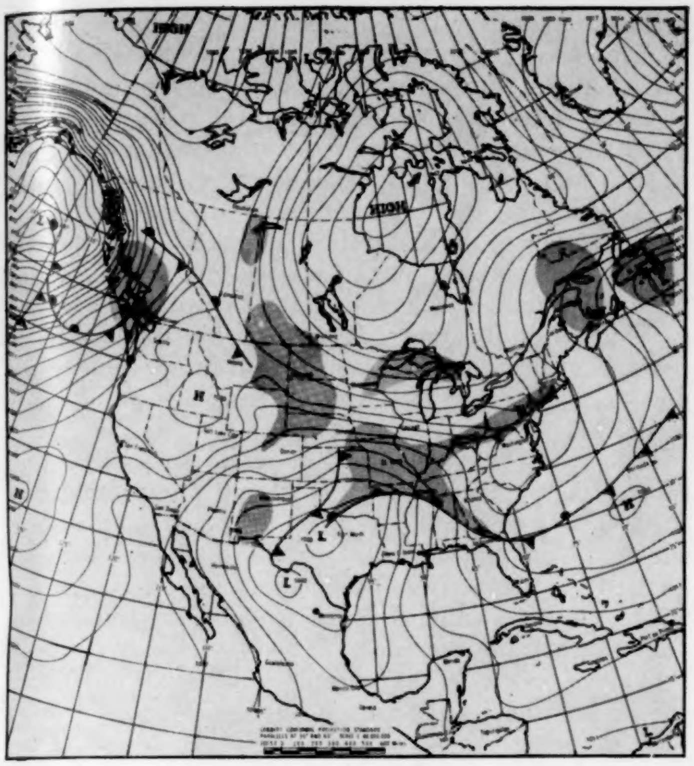

Figure 6.—North American surface map for 1830 GMT, February 12, 1950. Shading indicates areas of active precipitation.

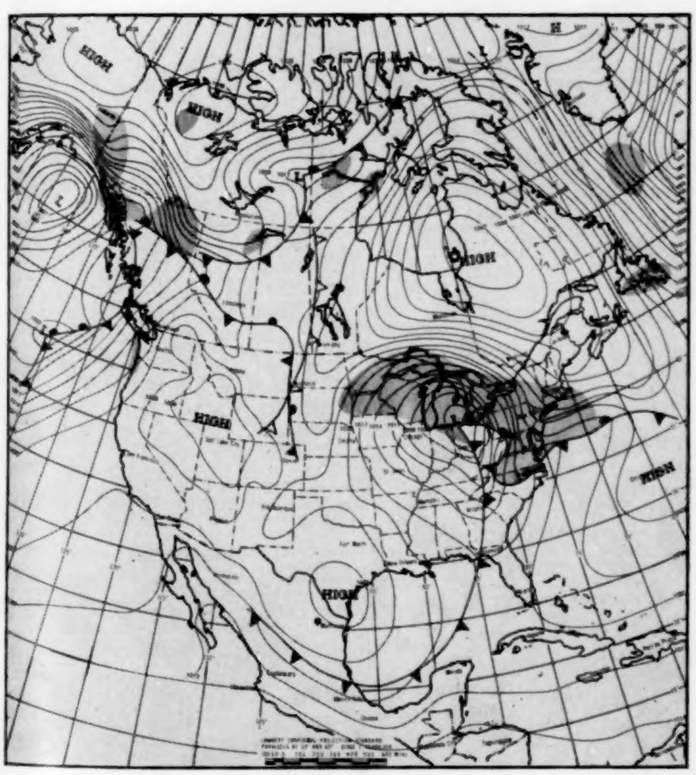

Figure 7.—North American surface map for 1830 GMT, February 14, 1950. Shading indicates areas of active precipitation.

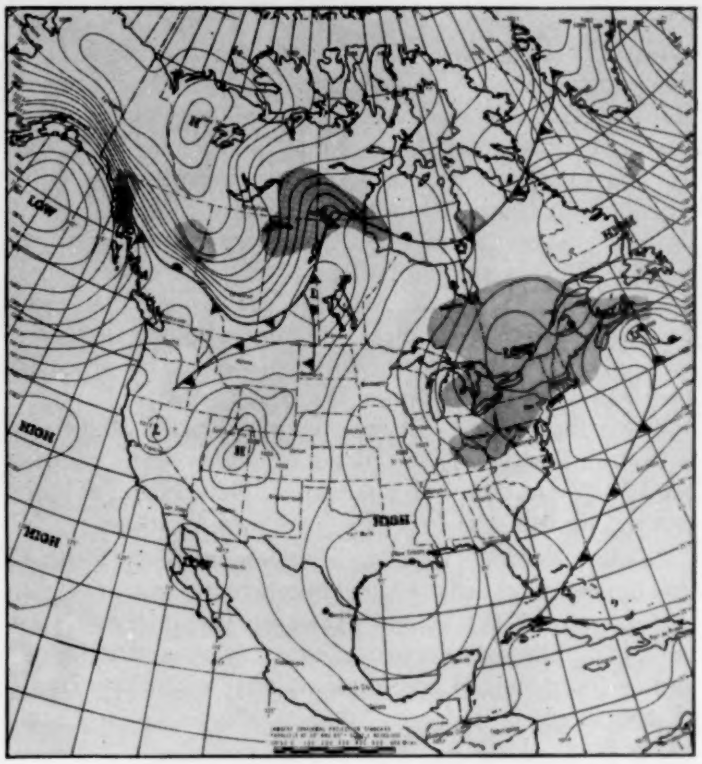

Figure 8.—North American surface map for 1830 GMT, February 16, 1950. Shading indicates areas of active precipitation.

As this Low moved eastward from the Lakes region (fig. 5) colder air from the Hudson Bay High, moving southward behind the Low, flooded the Northern Plains, Lakes region, and Northeastern States. This cold air may be seen on the surface weather map for 1830 GMT, February 12 (fig. 6) after the Low had moved into the Atlantic; it is north of the front extending from Connecticut to Indiana and over the area thence westward to the Rockies. However, temperatures were not unseasonably low.

Meanwhile, on February 10 (fig. 5), another surge of cold maritime air passed inland along the Pacific coast between Juneau and southern California. This deep mass of cold air had moved eastward and southward into the Texas and Oklahoma Panhandles and western Kansas by 1830 GMT of the 12th (fig. 6) at which time low pressure over Texas was associated with interaction between this cold maritime air and the colder air that had previously moved southward from the Hudson Bay High. Accompanying this condition, as shown on the chart for the 12th, was the only strong flow of tropical air northward from the Gulf of Mexico into the lower Mississippi Valley during the month of February. Also, surface pressure over Texas was by far the lowest during the month in that area. This low pressure intensified and moved northeastward. On the afternoon of the 14th (fig. 7) it was a well-developed cyclonic circulation centered over northern Ohio. Also, on the afternoon of the 14th, conditions were favorable for the formation of a secondary Low in the Chesapeake

Bay region. Aloft, a low-pressure trough, which was necessarily associated with the surface Low over Ohio, was moving eastward, accompanied by falling pressure along the Atlantic coast. At the same time cold maritime air was moving from the east into New Jersey and Delaware in such a way as to be deflected southward by the Appalachian Chain, while to the southward along and off the coast warm tropical maritime air was moving northward. The net result of these effects was to produce a secondary Low along the Atlantic coast which on the 15th was well developed and which produced the extensive snow cover over the Northeastern States. The secondary Low was off Nova Scotia on the 16th (fig. 8).

The extensive and rather heavy precipitation associated with both the main Low and the secondary was a result of the strong northward flow and consequent lifting of moist tropical maritime air over the deep cold air mass.

Another outbreak of cold air, which on the 16th (fig. 8) was approaching central Canada, moved across the northeastern part of the United States on the 18th and 19th, preserving the snow cover in that region and definitely ending the regime of unseasonably mild winter weather in that area.

FEATURES OF THE UPPER TROPOSPHERE

The preceding discussion outlines briefly some of the main synoptic features of the change in regime. Extreme cold in the Northwestern States moderated by the end of the first week in February but the final phase of the change in regime, marked by a change to colder and more normal weather in the eastern part of the country, took place only after an intervening series of synoptic events. These synoptic events, discussed so far mainly with respect to surface conditions, were accompanied by important changes of circulation in the upper troposphere, some aspects of which we examine in further detail in this section.

Upper air conditions are shown in figures 9–16 inclusive, the daily 500-mb. charts for 0300 GMT, February 8–15. On these charts a series of surges are followed, and their implied effect on the changing configuration of upper air pressure and flow patterns is discussed. For this purpose a surge is defined as the leading edge, marked by a wind shift or trough, of an area of strong wind. A good example of a surge is one which approached the coast of California and Oregon on February 10 (fig. 11); on the 11th (fig. 12) a secondary surge moved into central Oregon and northern California. A surge may or may not be associated with a front.

An attempt is made to follow in this series of 500-mb. charts an idea that has been utilized to some extent by the WBAN Analysis Center in forecasting changes in upper level configuration. This idea is, in substance, that a surge of more rapidly moving air parcels, on overtaking the trough line, contributes a portion of its kinetic energy toward sharpening the trough line, or conversely, as the surge deteriorates, the sharpness of the trough deteriorates. A sharpening of the trough is accompanied by some conversion of kinetic energy to potential energy (air parcels move outward across the isobars or contours toward higher pressure) and since this effect takes place in the middle and upper troposphere, it should result in lifting (and cooling) of air from below and "drawing down" of air from above in a region of resulting horizontal divergence. Some understanding of the kinematical, dynamical, and thermal results of this process aids in anticipating the changes of pressure pattern, surface and aloft, that will result from a surge or series of surges. It explains, not the large scale patterns of the upper troposphere, but rather some of the day to day changes in the meandering stream of upper westerlies.

In figures 9–16, trough lines or surges are indicated by symbols A, B, C, etc., with a subscript to indicate day of the month; for example, A_8 refers to trough A on the 8th and A_9 to the same trough on the 9th. These lines are referred to alternately as troughs or surges, depending on whether or not a surge is associated with the trough line.

In figure 9, the chart for February 8, it may be noted that along trough A_8 the reported winds south of latitude 45° N. and behind the trough, in Nevada, were weaker than the winds ahead of the trough. In Montana the winds were stronger than those reported in Minnesota. Thermal advection (warm advection indicating a rise and cold advection a fall of pressure) was an indication that the ridge along the ninetieth meridian would move rapidly eastward, and that pressures aloft along the ridge and immediately westward would fall. On the 9th (fig. 10) the trough A_9 was slightly sharper in the region of the western Great Lakes; the air then passing Sault Ste. Marie had moved through the trough and "overshot" it, being first decelerated and later deflected to the left upon entering the gradient east of the trough line. Meanwhile, the southern portion of the trough had advanced only slowly, the small trough in southwestern Utah on the 8th having been flattened into broad curves in the southern Plains area by the 9th. By the 10th (fig. 11) this trough was virtually spent. There was still a pattern for cold advection, suggesting some fall of pressure toward the east of trough A_{10}, but the gradient ahead of the trough was sufficient to deflect northeastward and accelerate slower moving air advancing through the trough line A_{10}, with consequent convergence that tended to offset any tendency toward rising pressure aloft in the middle Atlantic region.

Looking again at the chart for the 8th (fig. 9) we find trough B_8 off the Pacific coast. Its sharpness was not well defined because of scarcity of data in the area, but the wind report from the stationary ship at 50° N., 145° W. indicates that there was much stronger flow behind the trough than is suggested by the existing gradient along the British Columbia coast. On the 9th (fig. 10) there were two minor surges, B_9 and B'_9. The double structure here was evident once the system was over land, and it may have existed over the ocean, undetected, or it may have resulted from topographic effects.

For each of these troughs, B_9 and B'_9, the gradient and the wind upstream from the trough exceeded the gradient wind in the trough. Also, the air moving through the trough advanced into a region of weaker actual gradient, and as a result tended to follow a path somewhat south of the contour lines existing on the chart for the 9th.

Figure 11, for February 10, shows that troughs B_{10} and B'_{10} were still in evidence, but B'_{10} was weak. B_{10} was becoming the dominant trough as A_{10} weakened. The gradient winds over Montana and Wyoming exceeded those in the region of troughs B and B′. Also their direction led toward an area of weaker gradient in Illinois and Wisconsin. This called for a drop in pressure in the Lakes region as the air entering the region of weak gradient crossed contours toward the south, or away from the Lakes. The result may be seen on the chart for the 11th (fig. 12) where only a single trough, designated as B_{11}, is now in evidence. The same reasoning applies to the New England area for the 12th.

On the 9th (fig. 10) there was another trough in the Pacific, C_9, extending southward from the Low that had persisted in the Gulf of Alaska. Wind at 50° N., 145° W. had decreased since the previous day, and in the meantime warmer air had moved into that area accompanied by a marked rise in the height of the 500-mb. surface. The wind at 50° N., 145° W. (fig. 10) was about 15 knots stronger than the gradient wind for the contour spacing and curvature at the corresponding point along the trough. This means that such air parcels as were represented by this wind decelerated upon passing through the trough, then recurved sharply toward the northeast, carrying warm temperatures toward the British Columbia and southern Alaska coastal region, resulting in a rise of upper level pressure in that area. By the 10th (fig. 11) this had taken place.

Meanwhile the Low in the Gulf of Alaska had been deflected westward, the upper level pressures to the west and southwest of the Low falling as a deep cold air mass moved southward through western Alaska and then eastward around the Low. This movement of cold air southward, then eastward, becoming parallel to a sustained flow of warm air immediately southward and moving in the same direction, represented a buildup of solenoidal or potential energy, and also appeared as a strengthening of the gradient for westerly winds in the vicinity of latitude 45° N This strengthening of gradient deflected northward (or toward lower pressure) any air that was entering the area at this level. Then cross gradient flow accelerated it until its speed, and consequently the Coriolis force, was sufficient to recurve it toward the south. As it entered the area east of the strongest gradient, the Coriolis force deflected it farther southward toward higher pressure, especially as it passed into and through the trough C_{10}. This resulted in deceleration of the air parcels.

By the time of the chart for the 10th (fig. 11) this deceleration was taking place near the California coast, where kinetic energy was being spent partially in deepening the trough. The winds reported by an Air Force reconnaissance flight northwestward from the central California coast (fig. 11) were sufficiently strong for air parcels to move far toward the southeast in spite of the gradient. Gradient in the area into which these winds were moving was sufficiently weak, especially off the California coast, to permit a long cross-gradient trajectory before they could be decelerated sufficiently to recurve toward lower pressure. Considering the succession of parcels which were advancing toward the trough, each parcel passing through the trough would decelerate, contributing to the deepening and advance of the trough, and forming a pressure pattern into which each succeeding parcel would advance a little farther southward before it spent its kinetic energy in deepening the trough.

This resulting southward movement of mass, uncompensated by similar southward movements of mass in some area far to the north (in this case Alaska and northern Canada) required a fall of pressure aloft along the Pacific coastal areas, as was verified on February 11 (fig. 12).

On the 10th (fig. 11) there was a possible secondary trough forming at D_{10}. Its existence was not certain at this stage, but was indicated in reconnaissance wind reports near the California coast. By the 11th (fig. 12) the position for this trough and its existence seemed better established.

Meanwhile another trough, E_{11}, was becoming established in New Mexico. Winds at Albuquerque and Tucson bear out the idea that winds approaching trough C moved far to the south of the contour pattern until they were decelerated sufficiently for the weak gradient in trough C to recurve them northward. When recurved, they crossed contours toward lower pressure, being accelerated until again of sufficient speed to recurve to the right because of the Coriolis force. The leading edge of air moving in this scheme seems then to have been along E_{11}. Again, as with the system B, there may have been topographic effects which contributed to the observed effect.

Trough E persisted and advanced since the winds behind it were in excess of the gradient winds in the trough, and pressures in the trough fell because the speed of the wind in New Mexico and Arizona carried air well across the gradient in advance of the trough. Meanwhile trough C persisted because the gradient wind within the trough was slightly weaker than the wind reported on the California coast.

Meanwhile, surge D_{11} (fig. 12) was becoming a dominant feature. While C_{11} moved eastward, D_{11} was "crashing" southward, becoming sharper and deeper, and tending to merge with C_{11}. As a result, there was further deepening in the general trough somewhat ahead of trough D, as may be seen by comparing figures 12 and 13. On figure 13, the trough line C_{12} was discontinued north of the Low in Arizona and trough line D_{12} extended into the trough in

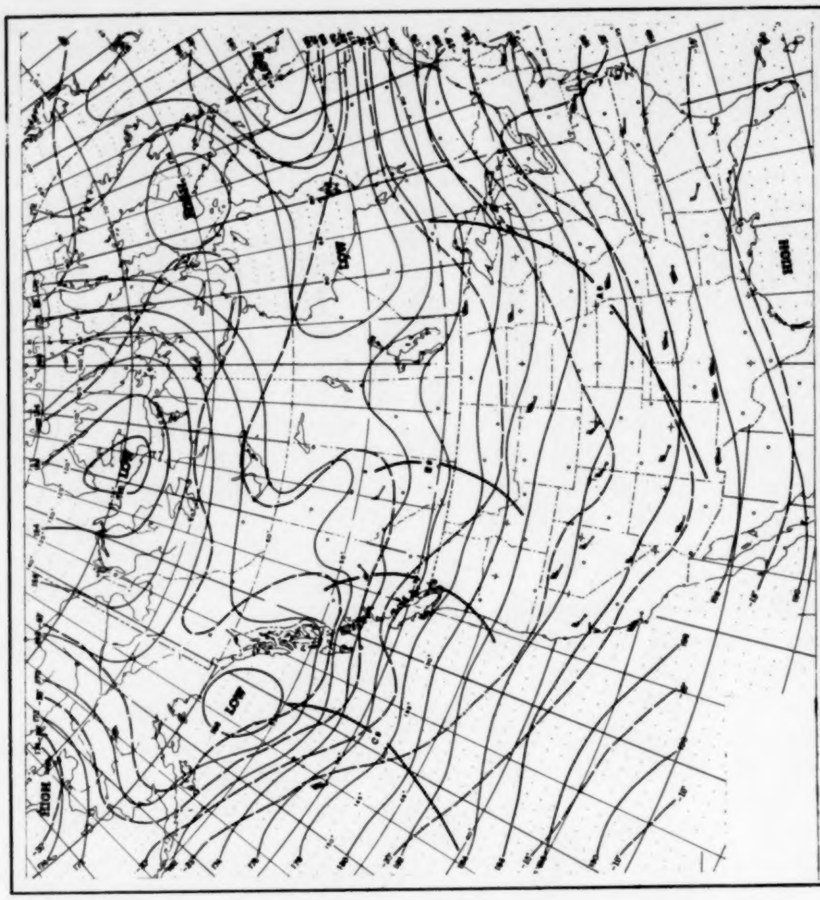

FIGURE 10.—500-mb. chart for 0300 GMT, February 9, 1950.

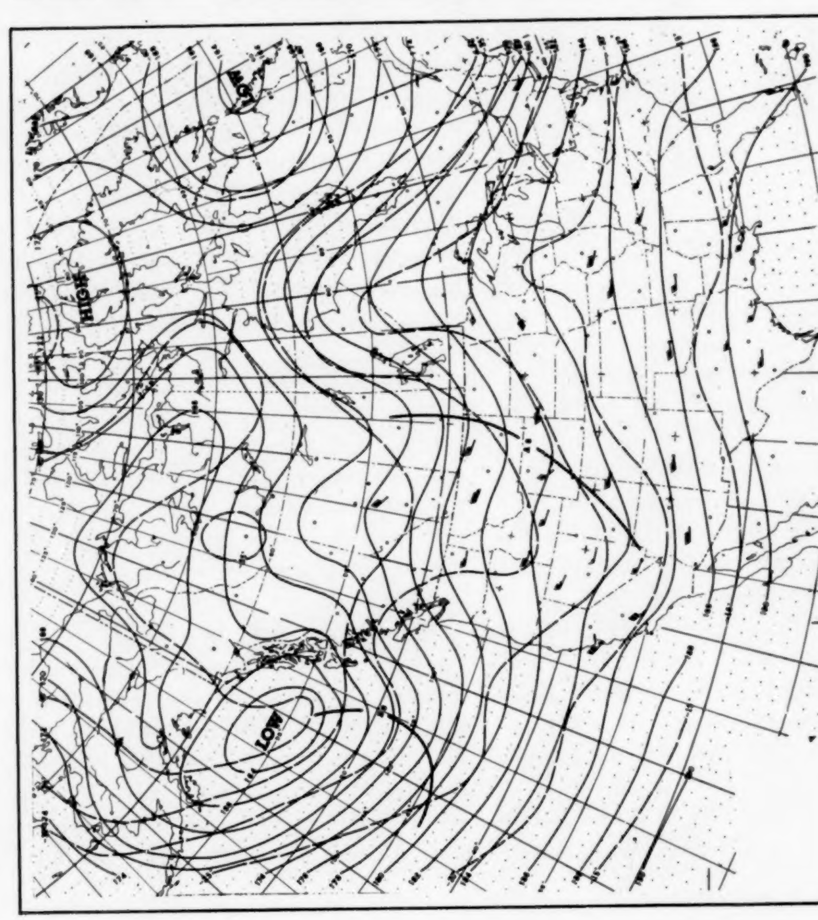

FIGURE 9.—500-mb. chart for 0300 GMT, February 8, 1950.

Contours (solid lines) at 200-foot intervals are labeled in hundreds of feet. Isotherms (dashed lines) are drawn for intervals of 5° C.

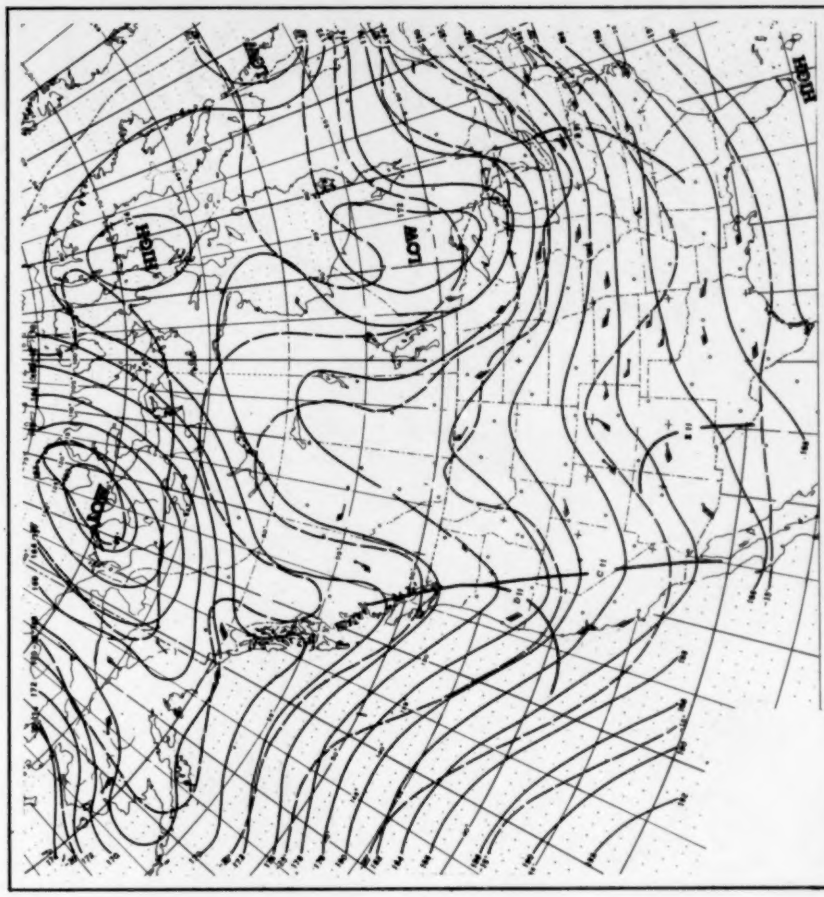

FIGURE 12.—500-mb. chart for 0300 GMT, February 11, 1950.

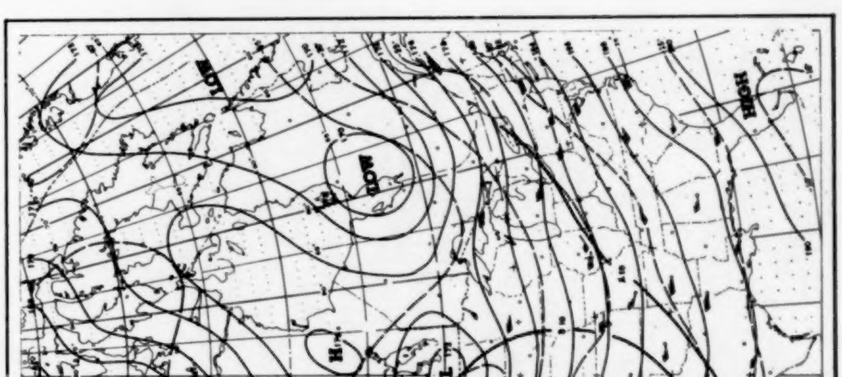

FIGURE 11.—500-mb. chart for 0300 GMT, February 10, 1950.

Contours (solid lines) at 200-foot intervals are labeled in hundreds of feet. Isotherms (dashed lines) are drawn for intervals of 5° C.

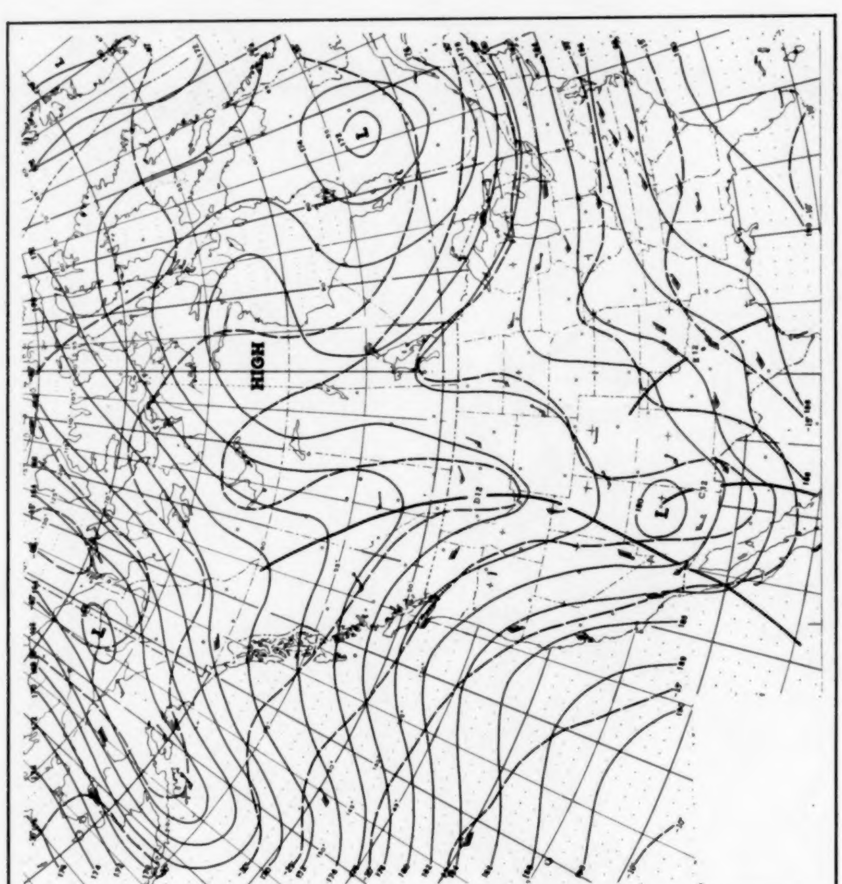

FIGURE 13.—500-mb. chart for 0300 GMT, February 12, 1950.

FIGURE 14.—500-mb. chart for 0300 GMT, February 13, 1950.

Contours (solid lines) at 200-foot intervals are labeled in hundreds of feet. Isotherms (dashed lines) are drawn for intervals of 5° C.

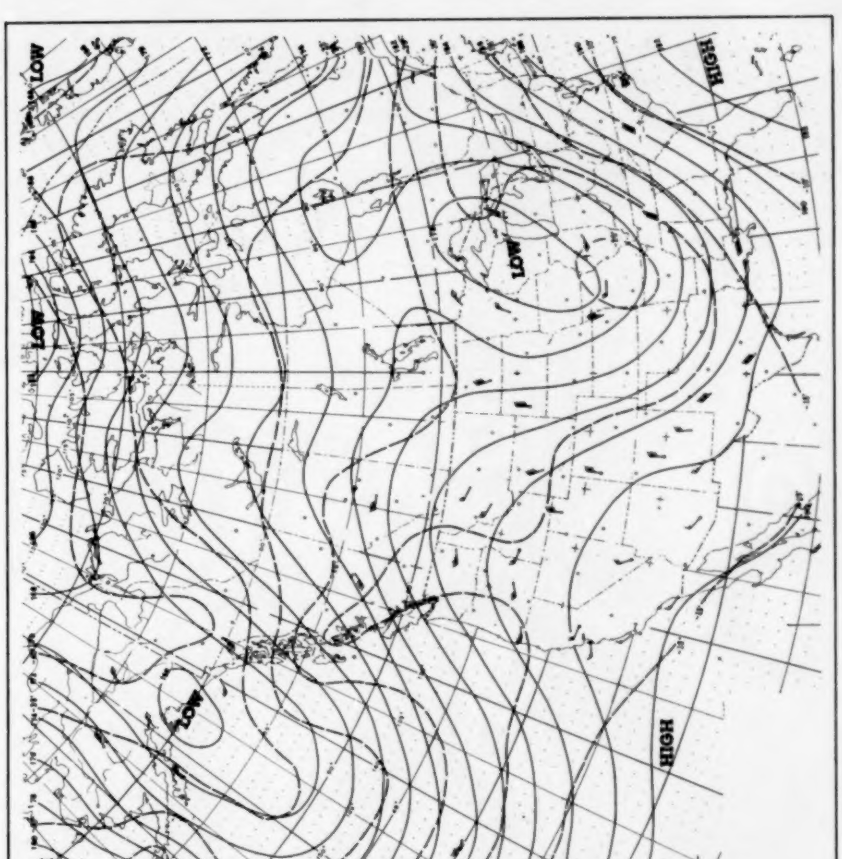

FIGURE 15.—500-mb. chart for 0300 GMT, February 14, 1950.

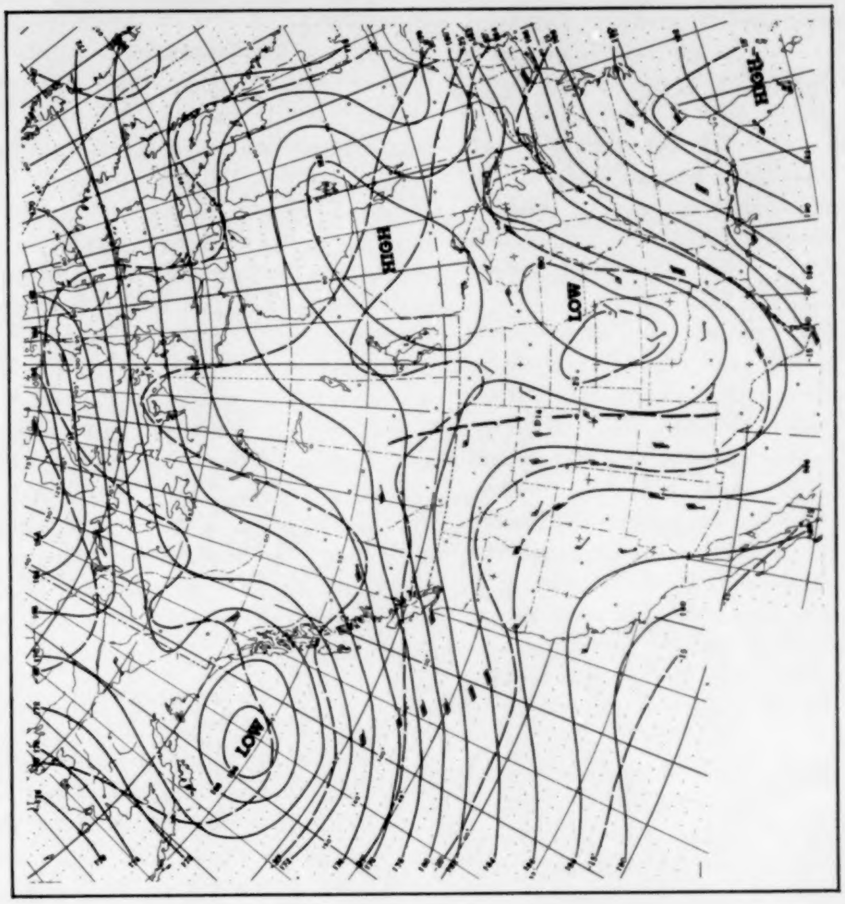

FIGURE 16.—500-mb. chart for 0300 GMT, February 15, 1950.

Contours (solid lines) at 200-foot intervals are labeled in hundreds of feet. Isotherms (dashed lines) are drawn for intervals of 5° C.

the north in order to emphasize the homogeneous character of the flow approaching this line, in contrast to the nonhomogeneous pattern in advance of trough D_{12}. From considerations similar to those already discussed, still further deepening was to be expected in the general trough ahead of D_{12} (fig. 13) in the southwestern part of the country. Farther north, particularly in Canada, winds to the west of D_{12} were weakening, indicating no further deepening of the trough in that area. The result is verified on the chart for the 13th (fig. 14).

On the 13th (fig. 14) the gradient was temporarily stronger on the west side of the Low which was then in New Mexico. This in turn accelerated the air moving into that region, as seen at Phoenix and Tucson, but otherwise the speed of winds upstream from the main trough had by then diminished. This chart (fig. 14) is the first of the series in which the speed of the air leaving the United States in the east approached or equaled that entering the country from the west. Except for strong winds in Arizona, and those entering the area of very weak gradient ahead of trough E_{13} and ahead of trough D_{13} in eastern Wyoming and eastern Montana, the winds were mostly in fair gradient balance with the gradients they were to enter.

Divergence occurred in Iowa because of the strong wind in Missouri, and in Nebraska and South Dakota in advance of the weakening shear line D_{13}. The strong wind in Arizona strengthened the gradient in the southeast part of Texas. The light winds in Colorado and New Mexico were deflected toward the lower pressures of the Low, and contributed convergence in the southwest limb of the Low. By the 14th (fig. 15) these effects were well toward accomplishment. The only winds then markedly nongradient in speed were the light winds between the Low and the decaying shear line D_{14}. These were to be deflected toward the southern portion of the Low and to aid in its northeastward acceleration. The result is shown in figure 16, the chart for February 15. Figure 16 represents the upper air pattern approximately 9 hours after the surface conditions shown in figure 7 for February 14.

The 500-mb. pattern of February 12 shown in figure 13 immediately preceded the development of surface storm conditions over Texas as shown in figure 6. The development of the surface storm was a necessary result of the lowering of upper-level pressure over the southern Plateau area and the advance of the upper-level low-pressure area eastward. The fall in pressure at the surface took place somewhat to the eastward of the upper-level fall of pressure because of northward low-level advection of warm air in advance of the upper-level trough, requiring from elementary hydrostatic relationships that the surface Low be east of the upper-level Low. Further intensification of the surface Low was aided by the already well-developed upper-level trough, and its northeastward movement was in response to the combined effect of eastward movement of the upper-level trough and the northward advection of warm air at low levels ahead of the upper-level trough.

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Chart I. Departure (°F.) of the Mean Temperature from the Normal, and Wind Roses for Selected Stations, February 1950

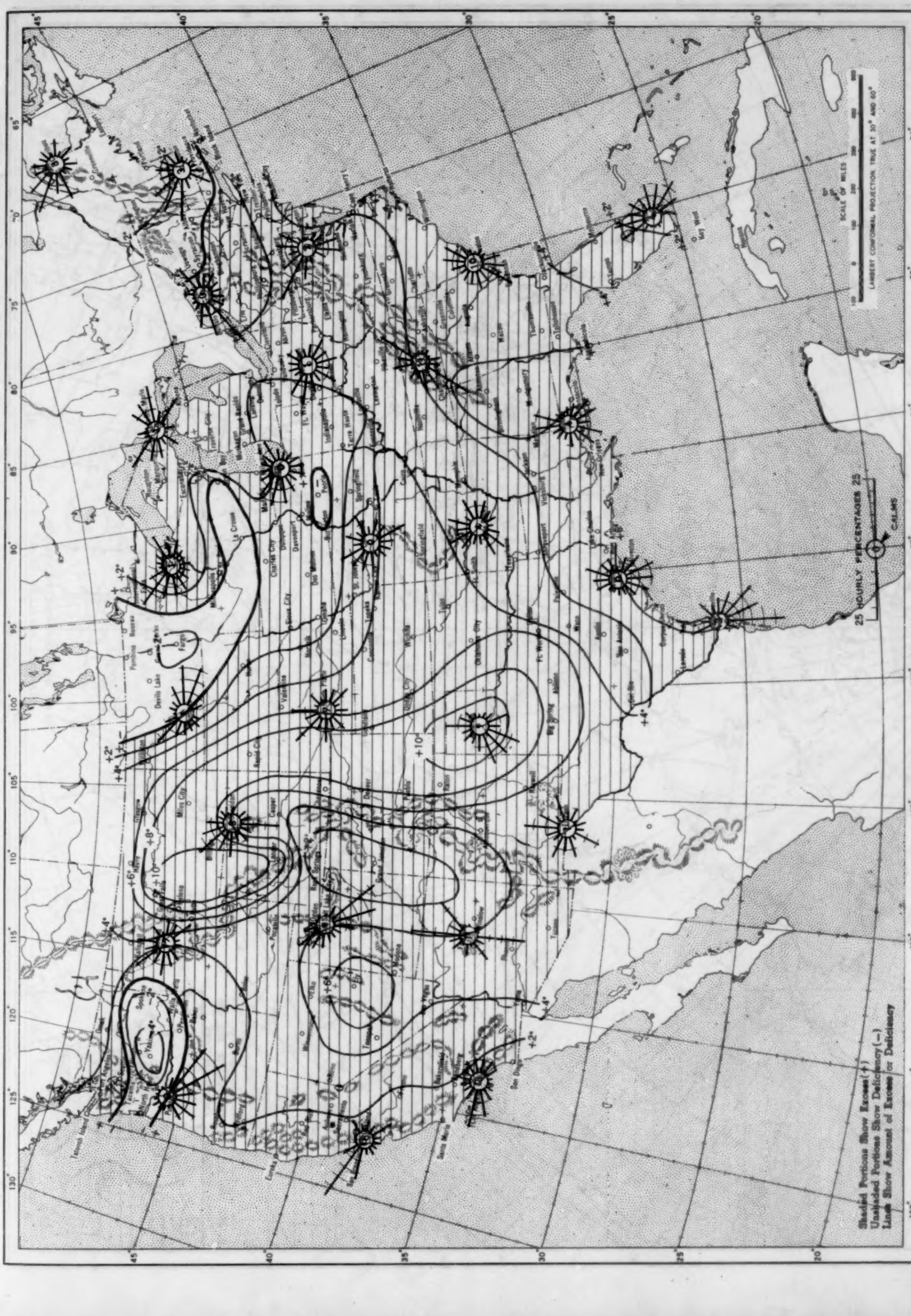
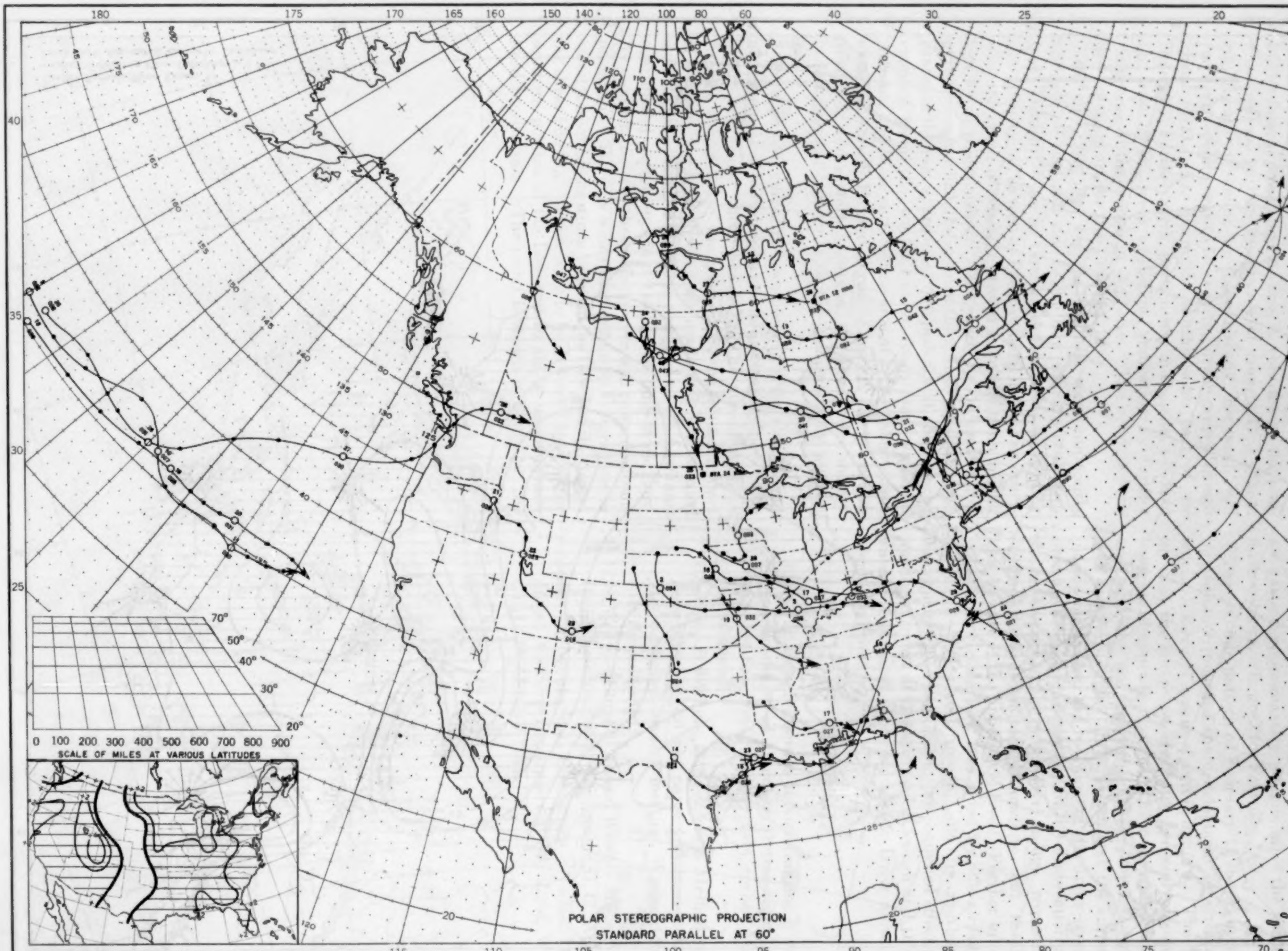
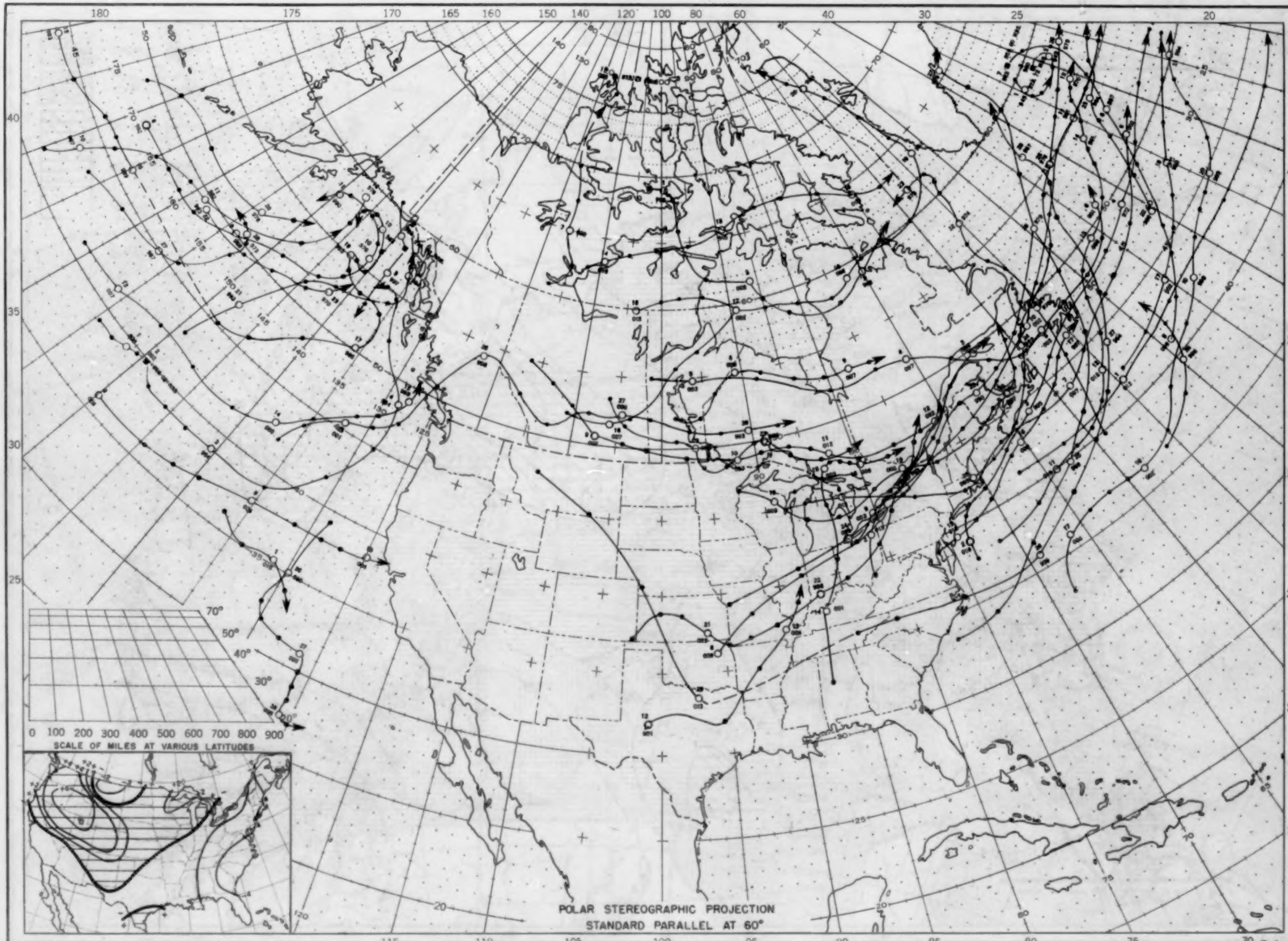


Chart II. Tracks of Centers of Anticyclones, February 1950. (Inset) Departure of Monthly Mean Pressure from Normal



Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time). Dots indicate intervening 6-hourly positions. Figure above circle indicates date, and figure below, pressure to nearest millibar. Only those centers which could be identified for 24 hours or more are included.

Chart III. Tracks of Centers of Cyclones, February 1950. (Inset) Change in Mean Pressure from Preceding Month



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time) Dots indicate intervening 6-hourly positions. Figure above circle indicates date, and figure below, pressure to nearest millibar. Only those centers which could be identified for 24 hours or more are included.

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, February 1950

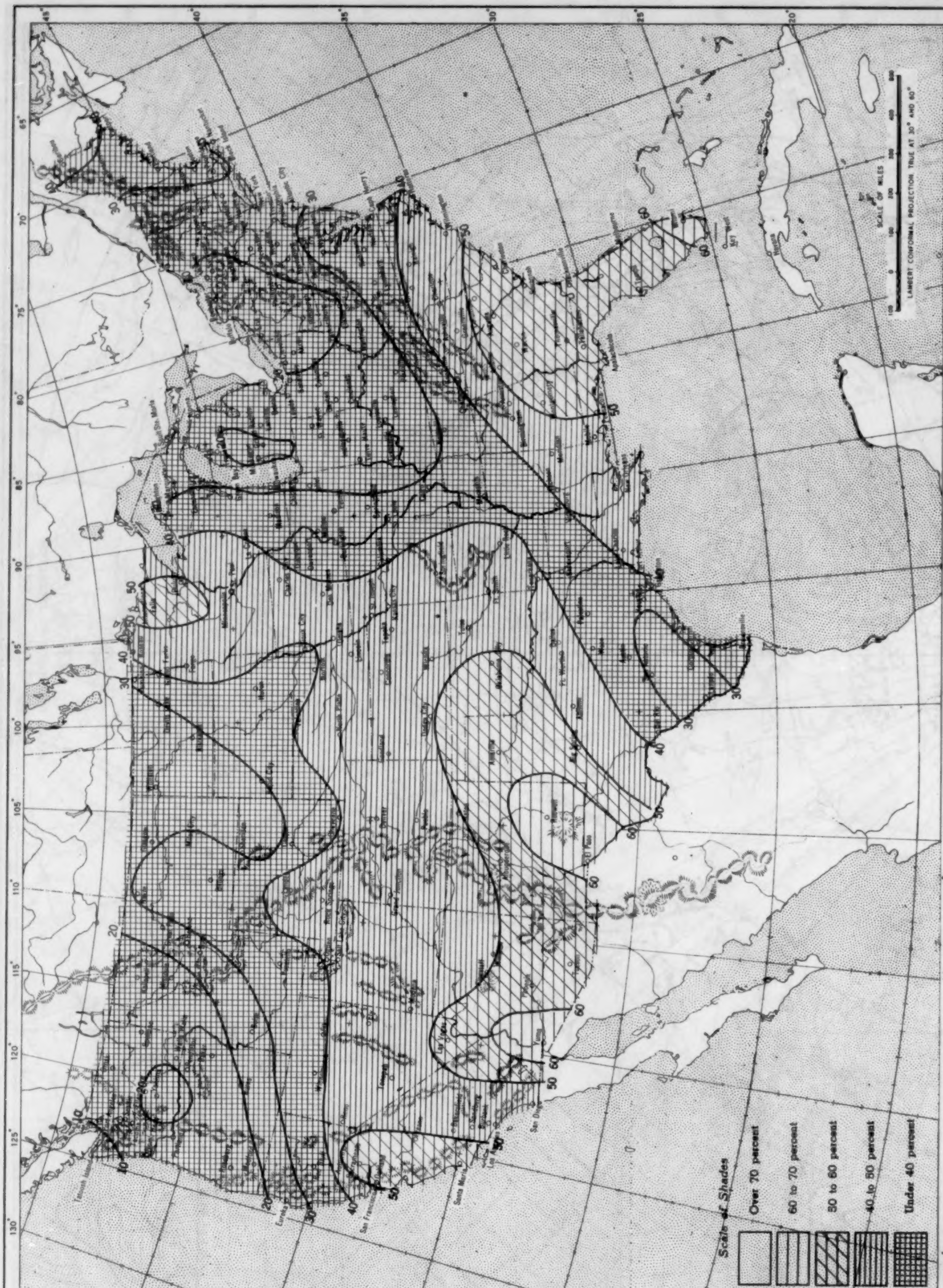


Chart V. Total Precipitation, Inches, February 1950. (Inset) Departure of Precipitation from Normal

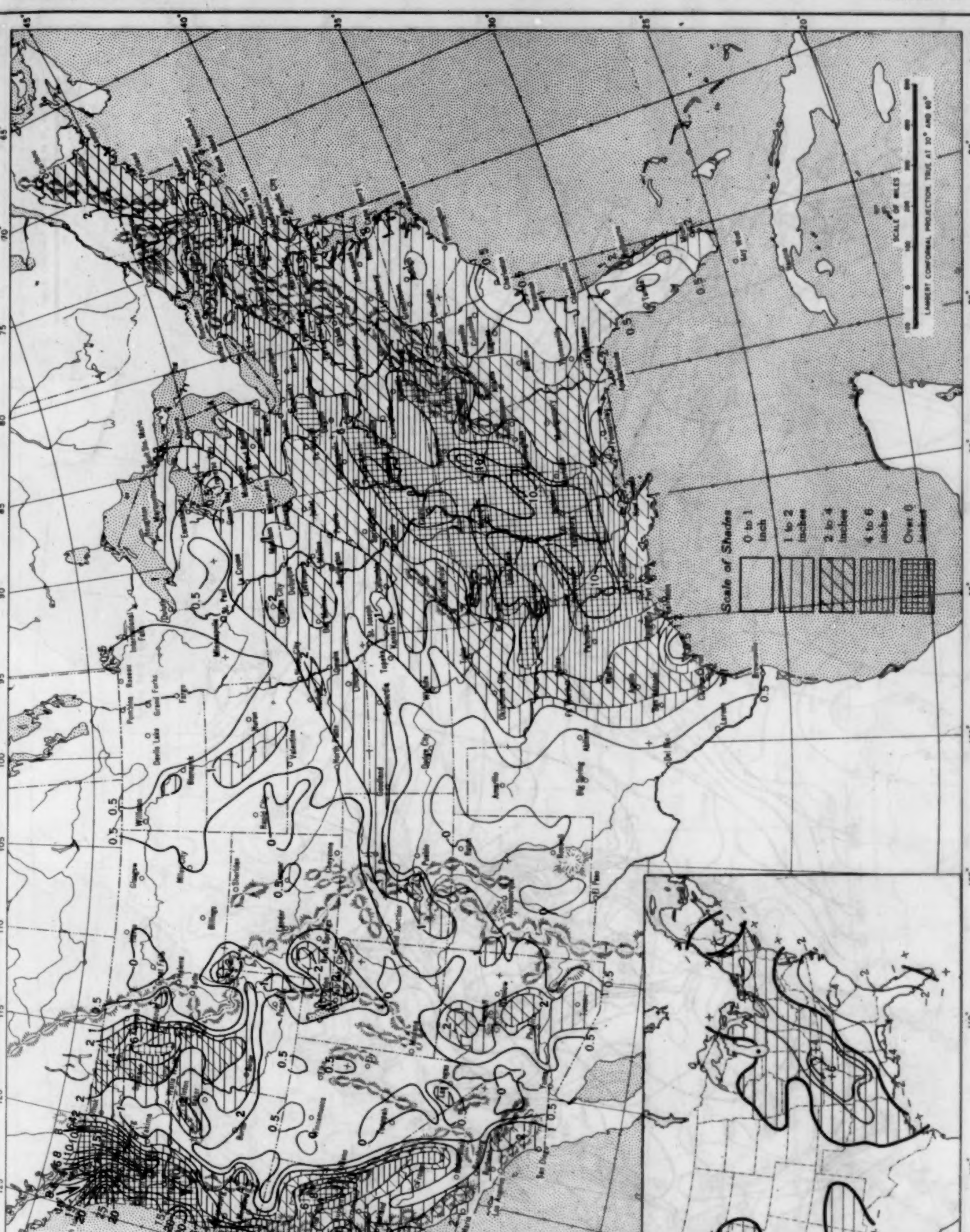


Chart VI. Mean Isobars (mb.) at Sea Level and Mean Isotherms (°F.) at Surface, February 1950

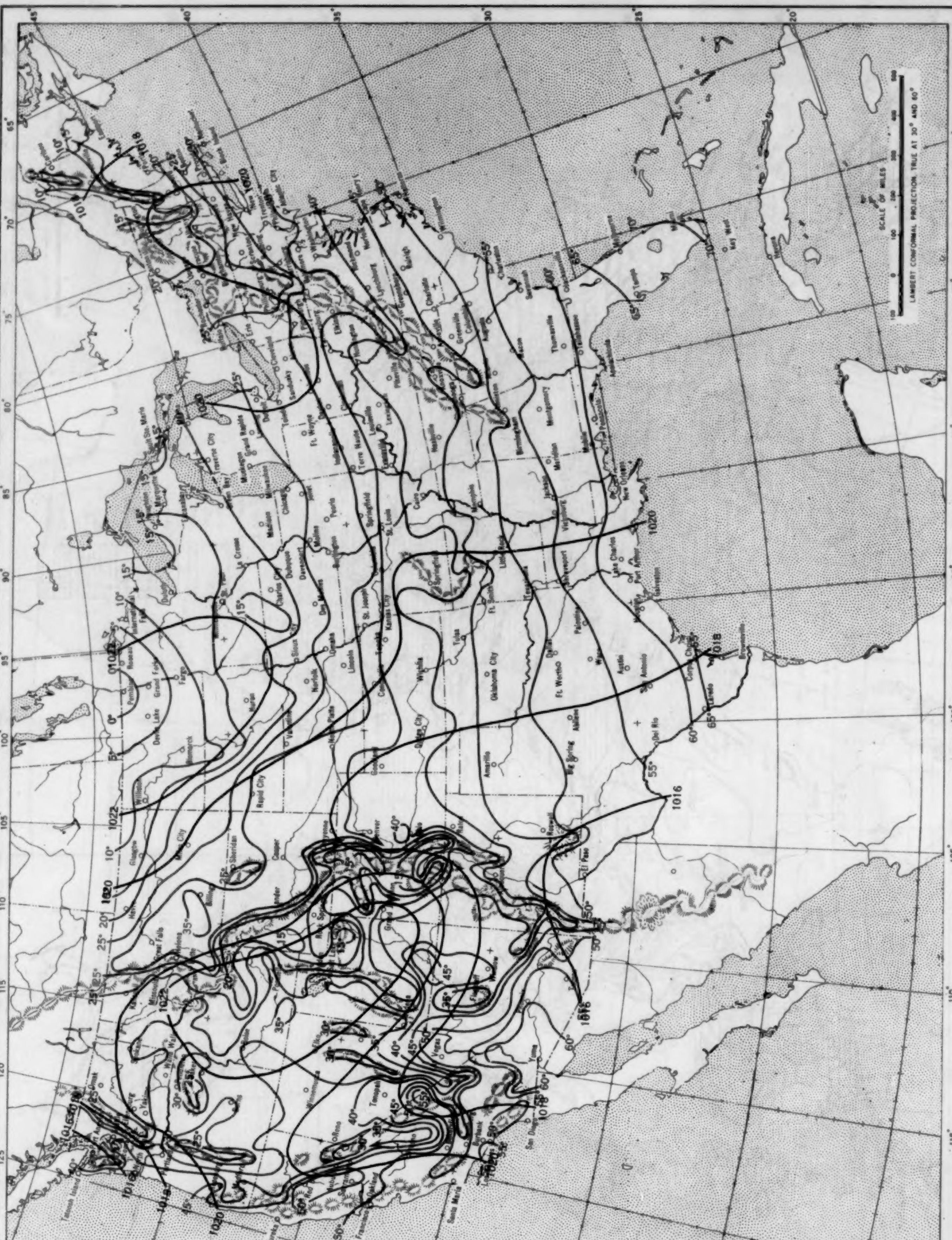


Chart VII. Total Snowfall, Inches, February 1950. (Inset) Depth of Snow on the Ground at 7:30 a.m., February 28, 1950

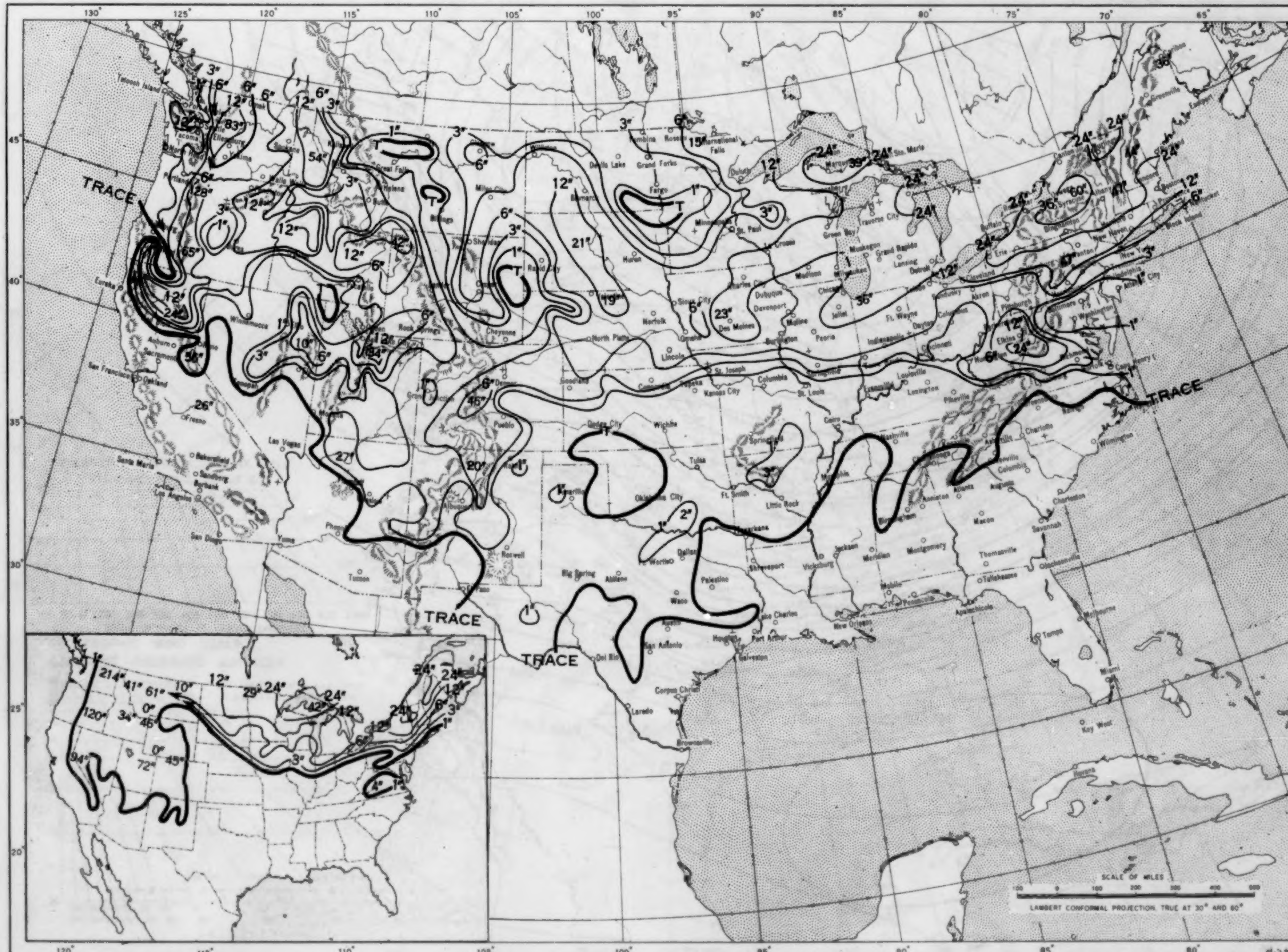
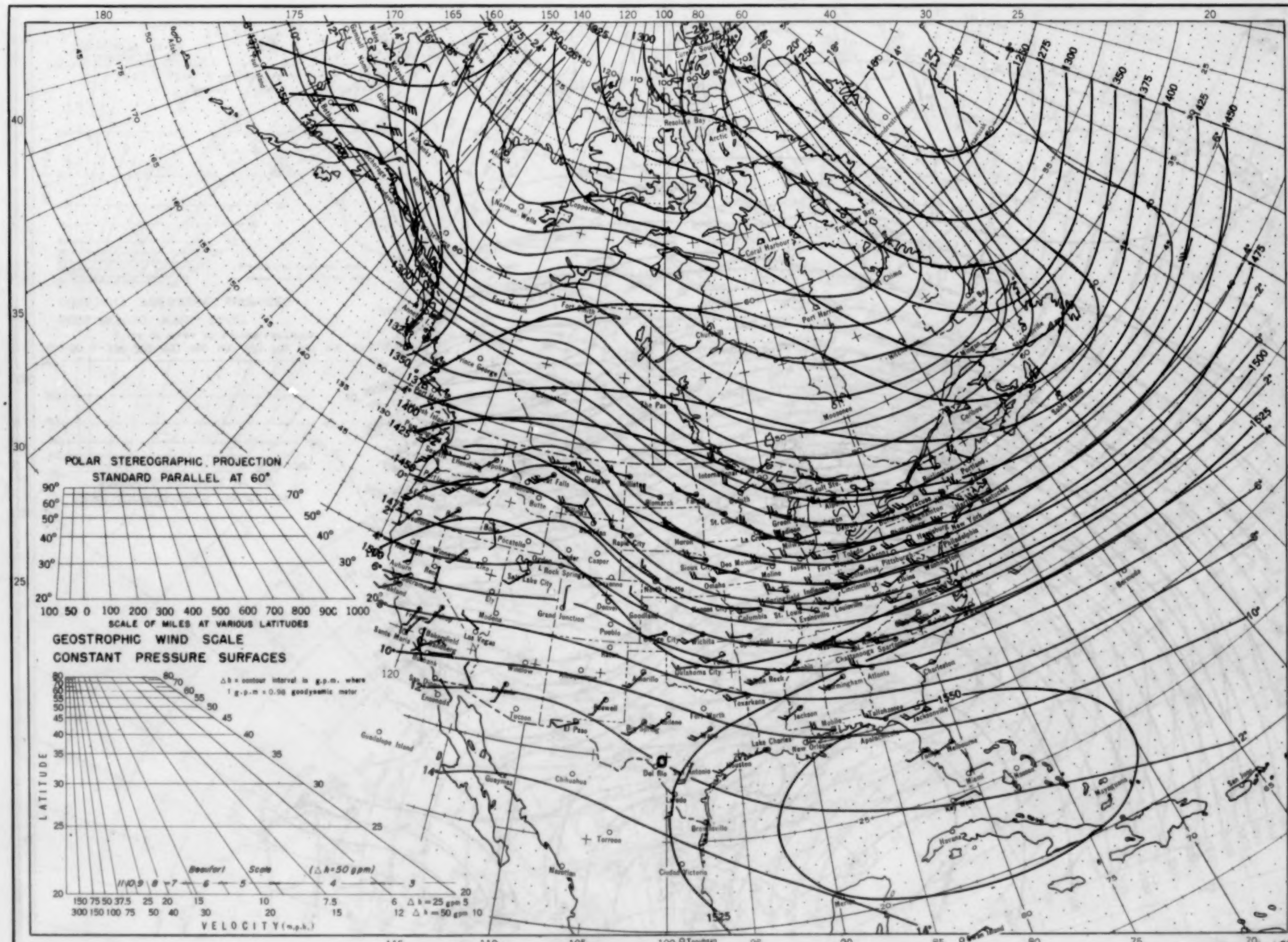
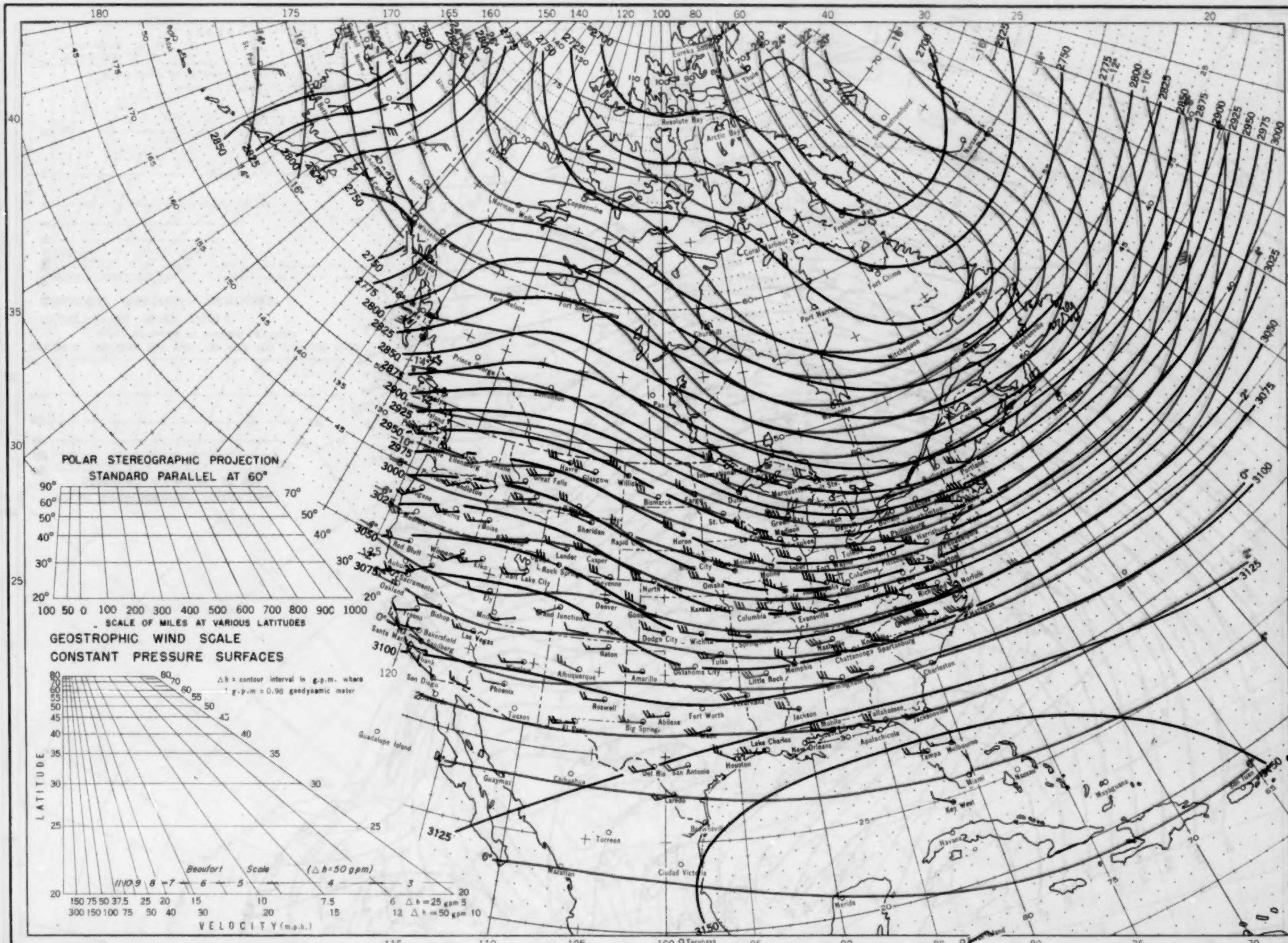


Chart VIII, February 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 850-millibar Pressure Surface, and Resultant Winds at 1,500 Meters (m. s. l.)



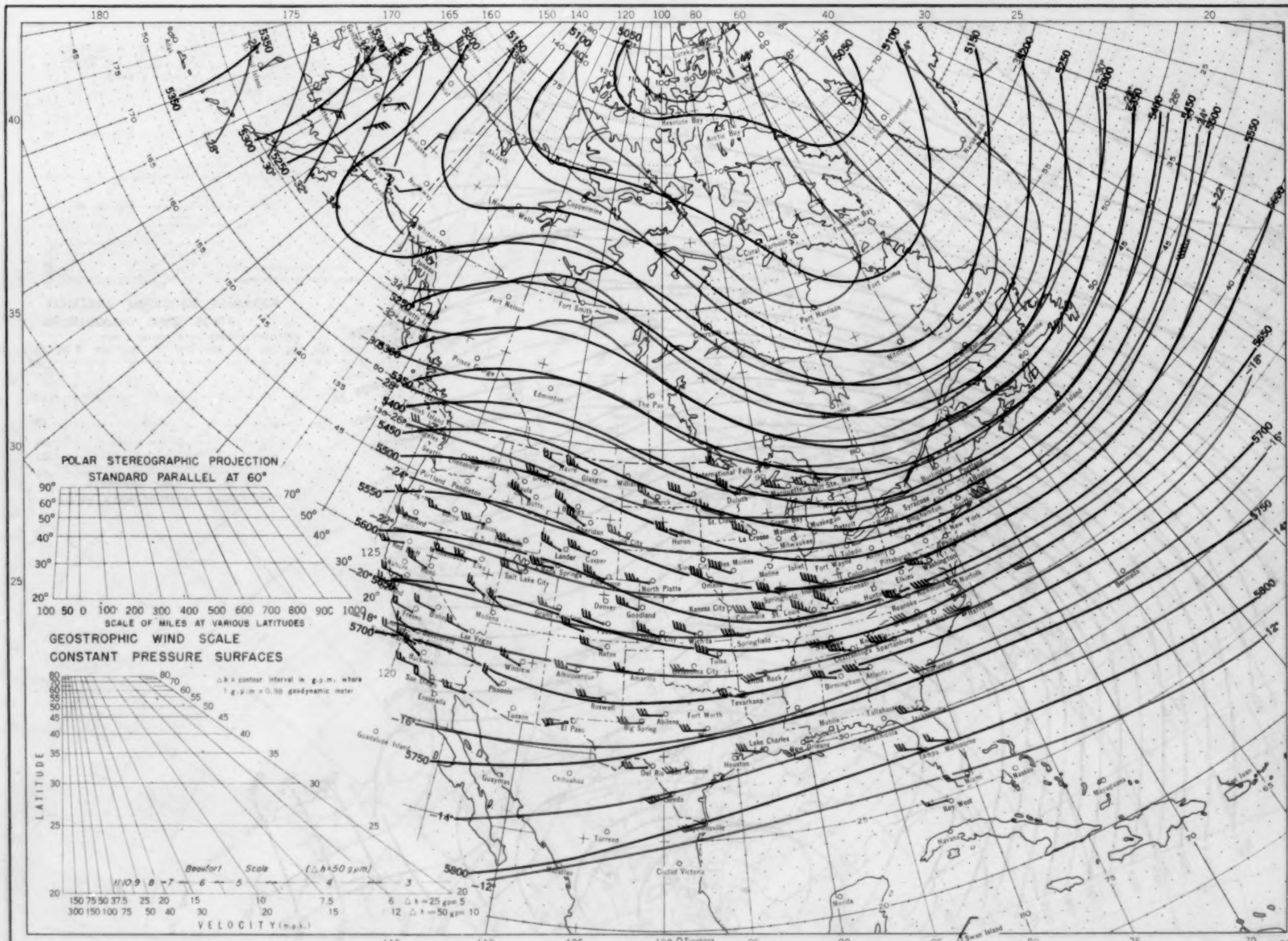
Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart IX, February 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 700-millibar Pressure Surface, and Resultant Winds at 3,000 Meters (m. s. l.)



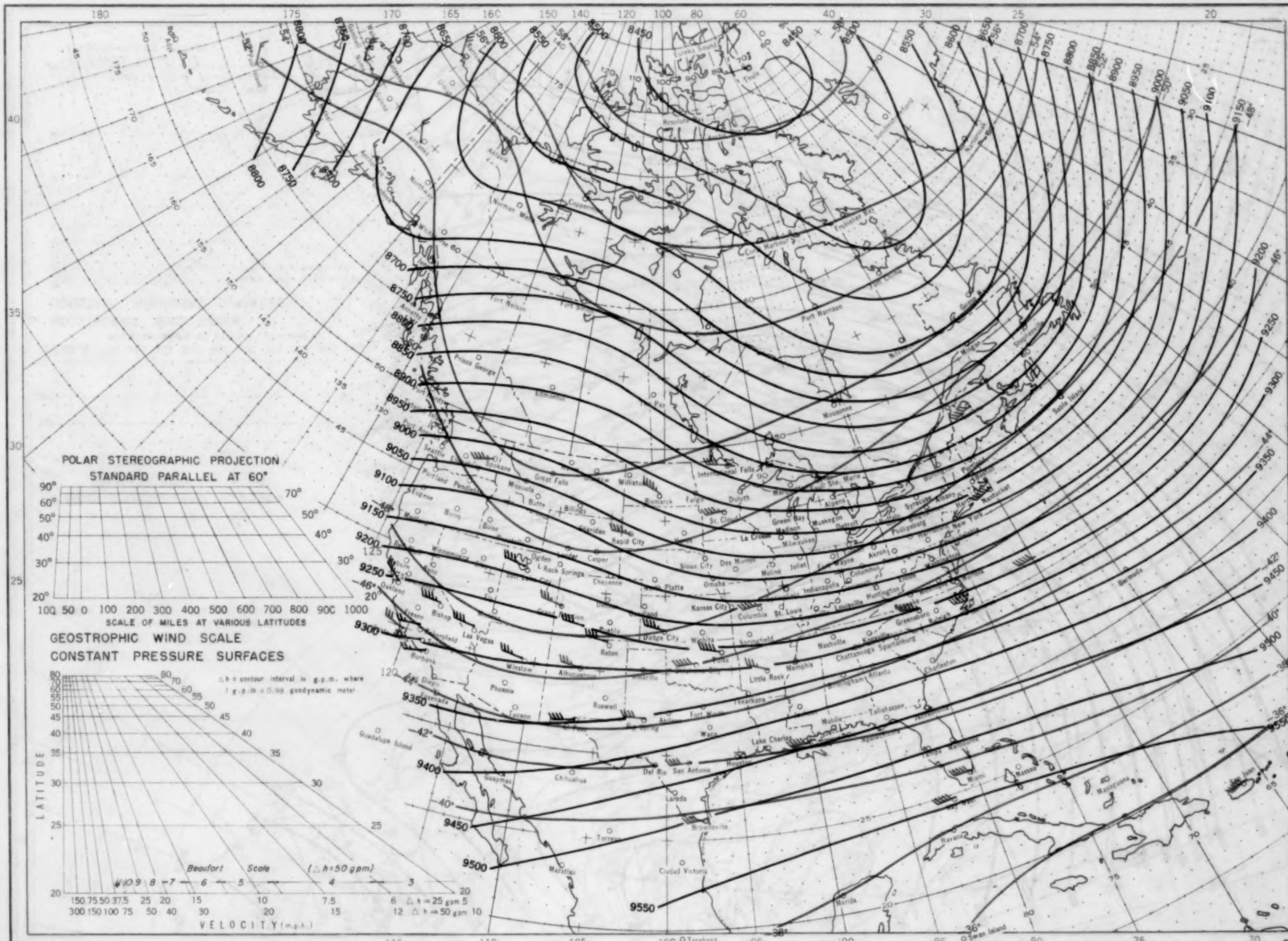
Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart X, February 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 500-millibar Pressure Surface, and Resultant Winds at 5,000 Meters (m. s. l.)



Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart XI, February 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 300-millibar Pressure Surface, and Resultant Winds at 10,000 Meters (m. s. l.)



Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.;
those indicated by red arrows based on rawins taken at 0300 G. C. T.